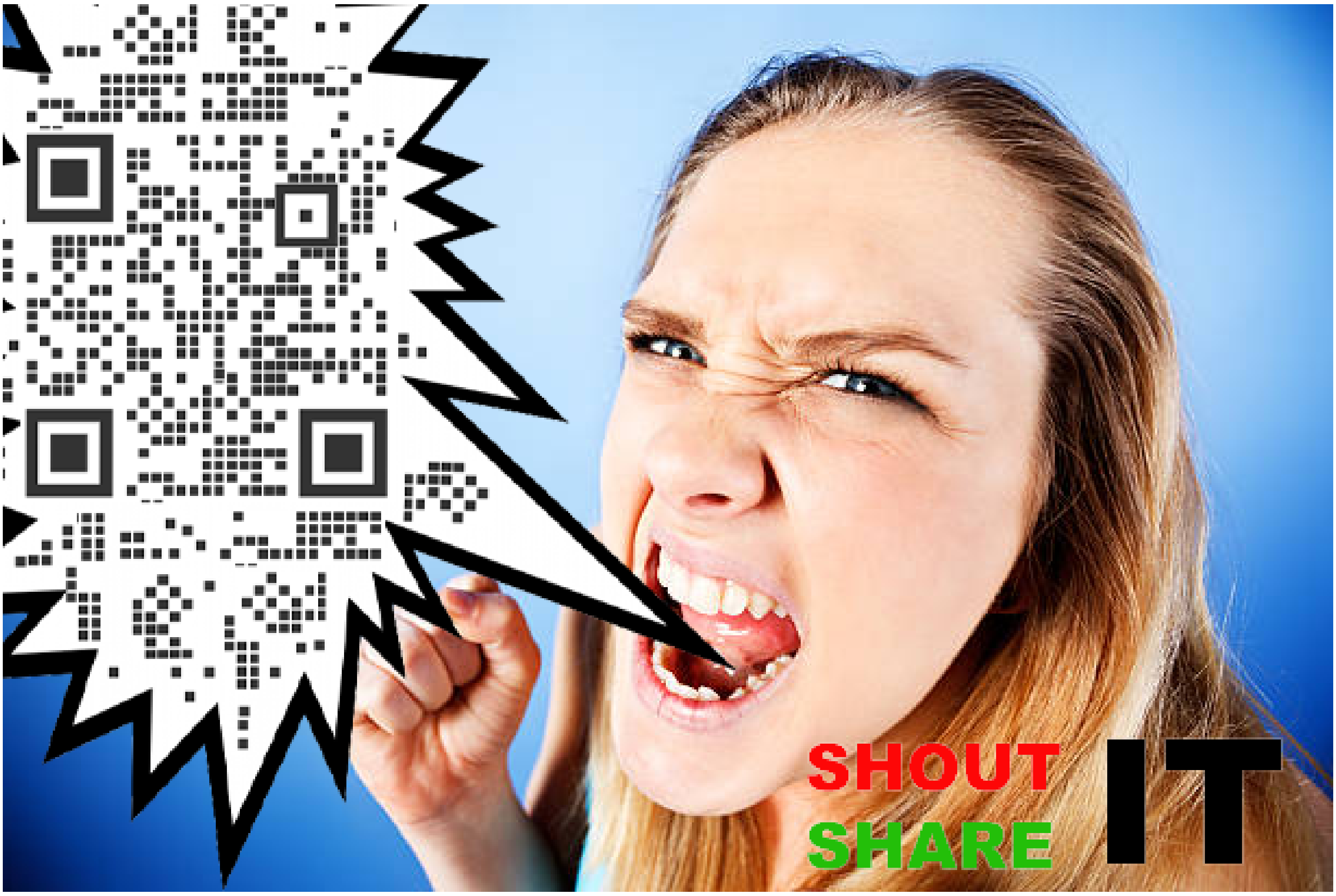
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Page 380, footnote; *for* "p. 1" *read* pp. 1-29
" 395, line 8 from top; *for* "faunas" *read* fauna

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 24, PP. 1-90, PLS. 1-4 MARCH 24, 1913

PROCEEDINGS OF THE TWENTY-FIFTH ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT NEW HAVEN, CONNECTICUT, DECEMBER 28, 29, 30, AND 31, 1912.

EDMUND OTIS HOVEY, *Secretary*

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Session of Saturday, December 28

The first general session of the Society was called to order at 9.38 o'clock a. m., Saturday, December 28, at Lampson Hall, Yale University, New Haven, Connecticut, by President Fairchild, who introduced Prof. L. V. Pirsson, who in turn welcomed the visiting geologists in the name of Yale University.

After making certain announcements the Secretary presented in printed form the annual report of the Council, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America, in twenty-fifth annual meeting assembled:

The regular annual meeting of the Council was held at Washington, D. C., in connection with the meeting of the Society, December 27 to 30, 1911.

The details of administration for the twenty-fourth year of the existence of the Society are given in the following reports of the officers:

SECRETARY'S REPORT

To the Council of the Geological Society of America:

Meetings.—The proceedings of the annual general meeting of the Society held at Washington, D. C., December 27 to 30, 1911, have been recorded in volume 23, pages 1–68; of the Cordilleran Section, pages 69–76, and of the Paleontological Society, pages 77–92, of the Bulletin.

Membership.—During the past year the Society has lost five Fellows by death: Ernest R. Buckley, Clarence E. Dutton, Thomas M. Jackson, W J McGee and Ralph S. Tarr; and one Correspondent, Ferdinand Zirkel. One resignation has become effective, and one Fellow has been dropped for non-payment of dues. The names of the twenty-nine Fellows elected at the Washington meeting have been added to the list, all of them having completed their membership according to the rule. The present enrollment of the Society is 342. Nineteen candidates for fellowship and three nominees to correspondentship are before the Society for election and several applications are under consideration by the Council.

Distribution of Bulletin.—Four new subscriptions to the Bulletin make the number of subscribers 109. Three names have been dropped from the exchange list, making the number of exchanges 63.* One copy was sent *gratis* to the Library of Congress.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 58; sold to Fellows, 1; sent out to supply deficiencies, 2, and delinquents, 2; brochures sent out to supply deficiencies, 34, and delinquents, 71; sold to Fellows, 21; sold to the public, 73.

Bulletin Sales.—The receipts from subscriptions to and sales of the Bulletin during the past year are shown in the following table:

---

* Vol. 23, p. 39, 7th line, should have read 66 instead of 65.

Bulletin Receipts, December 1, 1911–November 30, 1912

	Complete volumes.			Brochures.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1....	....	$15.00	$15.00	....	$1.15	$1.15	$16.15
Volume 2....	....	22.50	22.50	....	1.70	1.70	24.20
Volume 3....	....	22.50	22.50	....	1.75	1.75	24.25
Volume 4....	....	22.50	22.50	....	.60	.60	23.10
Volume 5....	....	15.00	15.00	....	.60	.60	15.60
Volume 6....	....	15.00	15.00	....	.80	.80	15.80
Volume 7....	....	22 50	22.50	$0.45	.15	.60	23.10
Volume 8...	....	22.50	22.50	.45	....	.45	22.95
Volume 9....	....	22.50	22.50	.50	.20	.70	23.20
Volume 10....	....	22.50	22 50	2.70	1.60	4.30	26.80
Volume 11....	....	22.50	22.50	....	....	....	22.50
Volume 12....	....	22.50	22.50	....	....	....	22.50
Volume 13....	....	15.00	15.00	.60	1.20	1.80	16.80
Volume 14....	....	15.00	15.00	....	3.00	3.00	18.00
Volume 15....	....	15.00	15.00	.40	1.10	1.50	16.50
Volume 16....	....	22.50	22.50	.90	....	.90	23.40
Volume 17....	....	7.50	7.50	....	5.50	5.50	13.00
Volume 18....	....	7.50	7.50	1.20	3.55	4.75	12.25
Volume 19....	....	7.50	7.50	....	3.15	3.15	10.65
Volume 20....	....	30.00	30.00	10.00	23.45	33.45	63.45
Volume 21....	....	52.50	52.50	....	14.50	14 50	67.00
Volume 22....	$7.50	130.00	137.50	21.40	53.25	74.65	212.15
Volume 23....	....	750.00	750.00	....	....	....	750.00
Volume 24....	....	45.00	45.00	....	....	....	45.00
Total...	$7.50	$1,345.00	$1,352.50	$38.60	$117.25	$155.85	$1,508.35
Index 1–10..	2.25	13.50	15.75	....	....	....	15.75
Index 11–20..	63.00	101.50	164.50	....	....	....	164.50
Total..	$72.75	$1,460.00	$1,535 75	$38.60	$117.25	$155.85	$1,688.60

Receipts for the fiscal year		$1,688.60
Previously reported		13,869.61
Total receipts to date		$15,558.21
Charged, but not yet received:	On 1910 account	10.45
	On 1911 account	11.00
	On 1912 account	101.30
Total sales to date		$15,680.96

One subscription to volume 23 is still to be paid for.

Expenditures.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURES OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1912

Account of Administration

Postage	$46.16	
Express	3.55	
Printing and stationery	131.25	
Copy of "American Men of Science"	3.00	
Messenger service	.20	
Dating stamp	1.50	
Electrotype of seal	.40	
Binding three copies of Bulletin	5.10	
Cordilleran Section (1911 and 1912)	72.41	
Total		$263.57

Account of Bulletin

Postage and express	$65.95	
Collection of checks	2.14	
Printing and stationery	1.25	
Envelopes for distribution of Bulletin	44.80	
Two photographs for Bulletin	2.00	
Telegrams and messenger service	3.00	
Jurat	.50	
Purchase of Bulletin	4.00	
Total		123.64
Total expenditures for the year		$387.21

Respectfully submitted,

EDMUND OTIS HOVEY,
Secretary.

NEW YORK, *December* 11, 1912.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending December 1, 1912.

One (1) Fellow—Burnett Smith—has commuted for life during the year by the payment of one hundred and fifty dollars, thus increasing the total Life Commutations, since the organization of the Society, to one hundred and three (103), which, with four (4) Honorary Life Members, makes a total of one hundred and seven (107). Three (3) Life Members died during the year (one of them an Honorary Life Member), which, with the eleven (11) previous deaths, leaves ninety-three (93) living Life Members.

Three (3) Fellows are delinquent for three years and three (3) Fellows are delinquent for two years, and are therefore liable to be dropped from the roll for non-payment of dues, in accordance with section 3, chapter 1, of the By-Laws; six (6) Fellows are delinquent for the present year, making a total of twelve (12) delinquents.

The membership of the Society, including delinquents, aggregates at the present time 342, of whom 93 have commuted for life. There have been five deaths during the year, one resignation, and one dropped from the roll. Twenty-nine Fellows were elected at the last meeting, all of whom have qualified.

With the advice of the Investment Committee, the Treasurer bought during the year two Consolidation Coal Company first and refunding mortgage 40-year 5 per cent sinking fund gold bonds, at a cost of $1,908.06, including accrued interest.

RECEIPTS

Balance in treasury December 1, 1911		$779.98
Fellowship fees, 1910 (5)	$50.00	
1911 (7)	70.00	
1912 (234)	2,340.00	
1913 (2½)	25.00	
		2,485.00
Initiation fees (29)		290.00
Life commutation (1)		150.00
Interest on investments:		
Iowa Apartment House Company	$50.00	
Ontario Apartment House Company	160.00	
Texas and Pacific Railroad bonds	100.00	
U. S. Steel Corporation bonds	150.00	
St. Louis, Iron Mountain and Southern Railroad bond	50.00	
St. Louis and San Francisco Railroad Equipment bond	50.00	
Fairmont and Clarksburg Traction bonds	100.00	
Consolidation Coal Company bonds	50.00	
Interest on deposits in Baltimore Trust Company	68.49	
		778.49
Case Library, third and final payment		750.00
Collection charges added to checks		.60
Received from Secretary:		
Sales of publications	$1,688.60	
Authors' separates	77.37	

Authors' corrections	27.00		
Collection charges added to checks	2.78		
		1,795.75	
			$7,029.82

EXPENDITURES

Secretary's office:			
Administration	$263.57		
Bulletin	123.64		
Salary	700.00		
		$1,087.21	
Treasurer's office:			
Postage, bond, safe deposit	40.00		
Allowance for clerical hire	50.00		
		90.00	
Publication of Bulletin:			
Printing[1]	$2,166.88		
Engraving	286.17		
Editor's allowance	250.00		
		2,703.05	
Purchase of two (2) first and refunding mortgage 40-year 5 per cent sinking fund gold bonds of Consolidation Coal Company, including interest		1,908.06	
Balance in bank December 2, 1912		1,241.50	
			$7,029.82

Respectfully submitted,

Wm. Bullock Clark,
Treasurer.

Baltimore, Md., *December* 1, 1912.

Editor's Report

To the Council of the Geological Society of America:

The Editor submits herewith his annual report. The following tables cover statistical data for the twenty-three volumes thus far issued:

Cost.	Average—Vols. 1-20.	Vol. 21.	Vol. 22.	Vol. 23.
	pp. 610. pls. 55.	pp. 839. pls. 54.	pp. 758. pls. 31.	pp. 758. pls. 43.
Letter press	$1,686.58	$2,049.95	$1,660.45	$1,750.40
Illustrations	390.99	404.27	260.81	274.70
	$2,077.57	$2,454.22	$1,921.26	$2,025.10
Average per page	$3.41	$2.93	$2.53	$2.62

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[1] This item includes transportation charges on the regular distribution of the Bulletin $37.40
and the following charges which have been refunded by the authors:
Authors' separates in excess of number given gratis by the Society 71.28
Authors' corrections in excess of allowance made by the Society 27.00

Classification.

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1.......	116	137	92	18	83	44	47	.....	60	4	4	593+xii
2.......	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3.......	56	41	44	41	32	158	104	.....	61	15	1	541+xii
4	25	134	38	74	52	52	14	.....	47	32	2	458+xii
5.......	138	135	70	54	28	51	107	.....	71	14	9	665+xii
6.......	50	111	75	39	71	99	1	.....	63	25	4	538+x
7.......	38	77	105	53	40	21	123	4	66	28	13	558+x
8.......	34	50	98	5	43	67	58	14	79	8	....	446+x
9.......	2	102	138	.....	44	28	64	16	64	12	....	460+x
10.......	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11.......	65	110	21	10	54	31	188	7	71	60	46	651+xii
12.......	199	39	55	53	24	98	5	5	70	2	....	538+xi
13.......	125	17	13	24	28	116	42	4	165	32	29	583+xii
14.......	48	47	48	59	183	118	22	1	80	14	1	609+xi
15	26	124	3	94	36	267	.....	.....	77	17	3	636+x
16.......	64	111	78	30	102	141	19	.....	67	22	15	636+xiii
17.......	49	161	41	84	47	294	27	.....	71	9	2	785+xiv
18.......	16	164	141	5	29	246	5	....	68	40	3	717+xii
19.......	106	108	29	66	30	155	32	....	56	15	20	617+x
20.......	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21.......	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22.......	23	54	28	28	23	403	74	.....	63	49	1	747+xii
23.......	75	52	126	108	19	145	134	.....	66	32	1	758+xvi

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor.*

COLDSPRING HARBOR, N. Y., *December* 16, 1912.

ELECTION OF AUDITING COMMITTEE

The Auditing Committee was then elected, consisting of Henry B. Kümmel, Whitman Cross, and Herbert E. Gregory, and the Treasurer's report was referred to it.

ELECTION OF OFFICERS

The Secretary declared the vote for officers for 1913 as follows, the ballots having been canvassed and counted by the Council in accordance with the By-Laws:

President:

EUGENE A. SMITH, University, Ala.

First Vice-President:

JAMES F. KEMP, New York City.

Second Vice-President:

R. D. SALISBURY, Chicago, Ill.

Third Vice-President:

C. D. WALCOTT, Washington, D. C.

Secretary:

EDMUND OTIS HOVEY, New York City.

Treasurer:

WILLIAM BULLOCK CLARK, Baltimore, Md.

Editor:

JOSEPH STANLEY-BROWN, Coldspring Harbor, N. Y.

Librarian:

H. P. CUSHING, Cleveland, Ohio.

Councillors:

WHITMAN CROSS, Washington, D. C.
WILLET G. MILLER, Toronto, Canada.

ELECTION OF CORRESPONDENTS

The following men were declared by the Secretary to have been elected in due form Correspondents of the Society:

Dr. **HERMANN CREDNER**, Geh. Rat., Dir. K. Sächs. Geol. Landesanstalt, Professor at the University, Leipzig.
Prof. W. **KILIAN**, Collab. princip., service de la Carte Géologique de France, Grenoble.
Dr. J. J. H. **TEALL**, Director of the Geological Survey of Great Britain, London.

ELECTION OF FELLOWS

The Secretary announced the election in due form of the following Fellows, the ballots having been canvassed and counted by the Council:

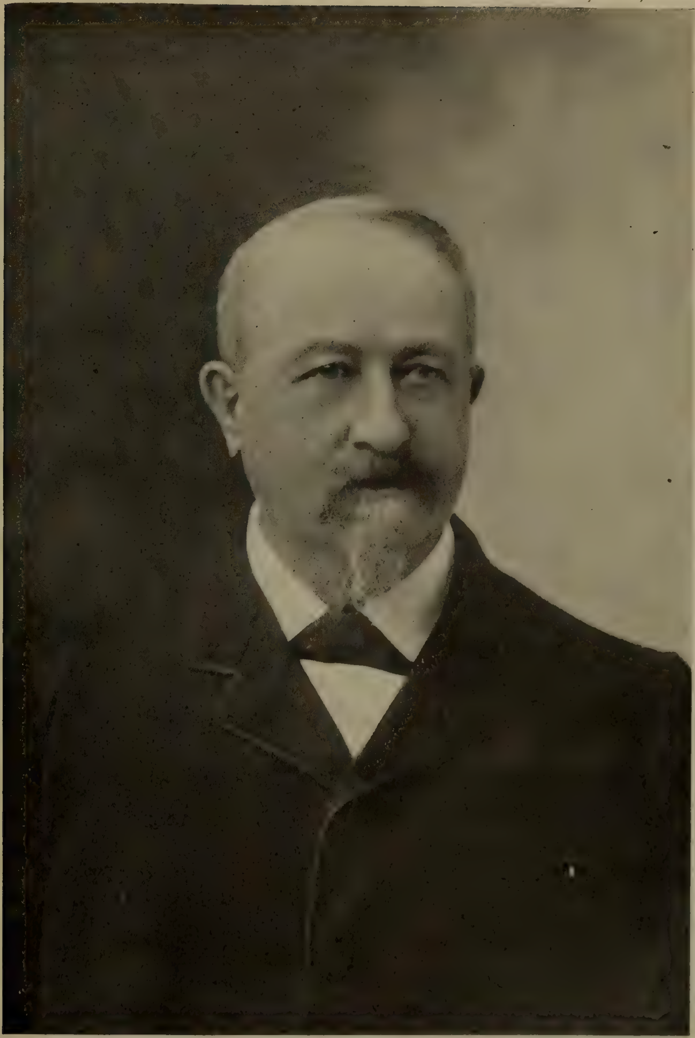
Bert S. Butler, A. B., A. M., U. S. Geological Survey, Washington, D. C.
Charles Butts, B. S., M. S., U. S. Geological Survey, Washington, D. C.
De Lorme Donaldson Cairnes, B. Sc., M. E., Geological Survey, Ottawa, Canada.
William Robert Calvert, A. B., U. S. Geological Survey, Washington, D. C.
William Harvey Emmons, A. B., Ph. D., University of Minnesota, Minneapolis, Minn.
Henry Hinds, B. A., U. S. Geological Survey, Washington, D. C.
Frank James Katz, A. B., U. S. Geological Survey, Washington, D. C.
Edwin Kirk, A. B., Ph. D., U. S. Geological Survey, Washington, D. C.
Laurence La Forge, A. B., A. M., Ph. D., U. S. Geological Survey, Washington, D. C.
Fred Howard Moffit, A. B., A. M. U. S. Geological Survey, Washington, D. C.
William Clifton Phalen, S. B., S. M., Ph. D., U. S. Geological Survey, Washington, D. C.
Louis M. Prindle, A. B., U. S. Geological Survey, Washington, D. C.
John Lyon Rich, A. B., A. M., Ph. D., University of Illinois, Urbana, Ill.
Alfred Reginald Schultz, B. S., Ph. D., U. S. Geological Survey, Washington, D. C.
Eugene Wesley Shaw, B. S., U. S. Geological Survey, Washington, D. C.
Claude Ellsworth Siebenthal, A. B., A. M., U. S. Geological Survey, Washington, D. C.
Carl Smith, B. A., U. S. Geological Survey, Washington, D. C.
Ralph Walter Stone, A. B., A. M., Ph. D., U. S. Geological Survey, Washington, D. C.
Carroll Harvey Wegemann, B. S., M. A., U. S. Geological Survey, Washington, D. C.

Announcement was then made that the Society had lost the following Fellows by death during the year 1912: E. R. Buckley, C. E. Dutton, T. M. Jackson, W J McGee, and Ralph S. Tarr, and one Correspondent, Ferdinand Zirkel. Memorials of deceased Fellows were presented as follows:

MEMOIR OF CLARENCE EDWARD DUTTON

BY J. S. DILLER

Major Clarence Edward Dutton, one of the first seismologists of his country, widely known for his reports on the Charleston earthquake, the high plateaus of Utah, and the Grand Canyon of the Colorado, was born May 15, 1841, at Wallingford, Connecticut, and died January 4, 1912, at Englewood, N. J. His parents were Samuel and Emily (Curtis) Dutton. At Ellington, Connecticut, he received his preliminary education, and in June 1856, entered Yale, where he graduated in 1860 with the degree of A. B., at the age of nineteen. April 18, 1864, he married Emeline C. Babcock, of New Haven, Connecticut.



C. E. Dutton
Capt Ord

He was appointed adjutant of the Twenty-first Connecticut Volunteers in September, 1862, and the following year, March 1, promoted to captaincy. In 1864 he was transferred to the Ordnance Corps of the Regular Army, and served through the remainder of the war. While assigned to the Watervliet Arsenal in 1865 he began his scientific studies, which, as he informed me, took two directions, and both were pursued with ardor. The first was invertebrate paleontology, under the guidance of Hall and Whitfield. The second was the study of steel, in cooperation with Alexander L. Holley, of the Bessemer Steel Works, of Troy.

At the end of five years he was transferred to Frankford Arsenal, Philadelphia, and thence to Washington, D. C. Being cut off from immediate contact with steel, his thoughts concentrated on geology, especially on the physical side of the subject. He became a member of the Philosophical Society of Washington in 1872, and met Professor Henry and Professor Baird, who took great interest in him. Through the former and Major Powell he was induced to consent to a detail for duty with the Powell Survey, beginning May 15, 1875.

He devoted ten years to the study of the great plateau region of the West, and published his results in the three reports entitled "The Geology of the High Plateaus of Utah" (6),[1] "The Tertiary History of the Grand Canyon District" (7), and "Mount Taylor and the Zuñi Plateau" (16). The plateau region of the West is remarkable, not only for the simplicity of its geological phenomena, but also for the variety and the enormous scale of the exposures.

Dutton's general conclusions are summarized in the closing chapter of the report on Mount Taylor and the Zuñi Plateau. Although contributing much to the geological history of the region, he evidently dwells with greater pleasure on the physical problems, and remarks, in describing the facts, that "not a trace of systematic plication has yet been found there," referring especially to the Zuñi part of the plateau region.

> "The terms anticlinal and synclinal have almost dropped out of the vocabulary of the western geologist. The strata are often flexed, but the type of flexure is the monocline.
>
> "The country at large shows no traces of a widespread, universal horizontal compression; on the contrary, it discloses the absence of such stress. We seem here to get nearer to the real nature of the process which has built the mountains. Shorn of that extreme complexity which confuses and bewilders us in more highly developed structures, the great central facts and the true essence of the mechanical processes involved become much clearer. The mountains of the West have not been produced by horizontal compression, but by the action of some unknown forces beneath, which have pushed them up."

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[1] The numbers in ( ) refer to list at end of this article.

The greatest problems of physical geology, according to Dutton (21), are: First. What is the potential cause of volcanic action? Second. What is the cause of elevation and subsidence of restricted areas of the earth's surface? Third. What is the cause of the foldings, distortions, and fractures of the strata?

The first two of these he regarded as being without satisfactory explanation, and for the third he proposesd a solution in elucidating his theory of isostasy. After having shown that the contractional hypothesis is quantitatively insufficient and qualitatively inapplicable in explaining the folding of the earth's crust, he presented in a modified form and greater detail the theory propounded many years ago by Babbage and Herschel. It was pointed out that the unloading of the land by erosion and the loading up of the sea floor by deposition resulted in a force which tends to push the loaded sea bottoms inward upon the unloaded land horizontally—a force of the precise kind that is wanted to explain the origin of systematic plication.

This view of the essentially isostatic condition of the earth, for which he invented the name *isostasy*, has been in recent years most ably advocated, and in fact practically demonstrated, by Prof. John F. Hayford.[2]

Dutton began the study of the volcanic problems early in his geological career, and his first papers in the Geological Survey (4) pertained to volcanic products. In his study of the plateau region he had abundant opportunity to observe an extensive and profoundly interesting series of complete and dissected volcanic as well as plutonic masses. In 1882 he visited the Hawaiian Islands to study Kilauea, Mauna Loa, and the other great volcanoes of that region (12) before beginning his survey of the great volcanic field of northern California and Oregon, where in 1885 he made a special study of Crater Lake and recognized its similarity to the great calderas of Hawaii (18).

He returned to military duty in September, 1890, and went to Central America and Lake Nicaragua. In 1891, while on duty at San Antonio, Texas, he made frequent excursions to the volcanoes of Mexico.

In 1899 he was recalled to duty in the office of the Chief of Ordnance in Washington, and on February 7, 1901, at his own request, was retired from active service.

One of Dutton's most notable contributions to science recognizes gravity as an essential factor in causing volcanic eruption. He was much impressed by Richthofen's order of succession in the eruption of massive rocks, beginning with propylite, a rock of intermediate composition, and followed by two series, one a lighter but less fusible acid series ending in rhyolite, and the other, a heavier though more fusible basic series, ending in basalt.

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[2] The figure of the earth and isostasy. Coast and Geodetic Survey Report, 1909; also supplementary investigations. Coast and Geodetic Survey Report for 1910, and isostasy, a rejoinder to the article by Harmon Lewis. Journal of Geology, vol. xx, p. 562. Sept.-Oct., 1912.

By a comparison of the chemical composition, density, fusibility, and physical aspects of these igneous rocks with one another and the lighter rocks up through which they were erupted, Dutton was led to the conclusion that "it is the gross weight of the overlying cover of solid rocks which presses the lava upward through any passage where it can find vent" (page 131, Geology of High Plateaus), and that the succession is a double sequence determined by density and fusibility. Concerning the origin of this view in his own mind, Dutton remarks (footnote, page 131, Geology of High Plateaus):

> "It was when I was contemplating the great distances traversed by slender basalt streams in southern Utah that this theory suggested itself to me. I had no doubt that such lavas must have been ejected at a temperature much more than sufficient to melt them. This seemed to contrast powerfully with the habits of trachytic masses. It occurred to me then that this high temperature might be absolutely essential to the eruption of so dense a rock as basalt, while a considerably lower one would suffice for lighter rocks. Immediately the higher melting temperature of the rhyolites and trachytes suggested itself, and almost as quickly as I write it the theory took form in my mind and the double function of density and fusibility associated itself with a double sequence."

In a letter October, 1911, he writes:

> "The subject of volcanoes and volcanic action had become of paramount interest to me, and I resolved to grapple with the problem. All existing theories seemed to me insufficient, and I became a confirmed skeptic as to the cause of volcanic action.
>
> "From 1875 to 1885 I continued to labor with the problem, but could only conclude that the cause was the local accumulation of heat; yet no reason for it appeared. For a time it seemed possible that the intrusion of basaltic masses among the sedimentaries might lead to chemical reactions which would furnish the necessary heat, as Prof. Reginald A. Daly so ably proposes in his recent theory of volcanic action. But after long reflection I could not accept that view, and concluded that as science then stood a solution was impossible, and it would be necessary to wait until some discovery should put another face upon the subject.
>
> "A discovery of prime importance—that of radioactivity—was made in 1897, which seemed to furnish the explanation of the necessary amount of heat near the earth's surface."

His final conclusions on volcanoes and radioactivity were presented to the National Academy of Sciences, April 17, 1906 (26).

Dutton made a special study of the Charleston earthquake in 1886 and devised a new method of ascertaining the depth of the earthquake focus, and measured with greater accuracy than ever before attained the rate at which an earthquake wave is propagated. His isoseismal method of computing the depth of focus involves the determination of two critical points: First, the epicentrum, and, second, a point on a radius from the epicentrum at which the intensity of shock diminishes most rapidly. A line drawn around the epicentrum through the points of most rapid change of intensity Dutton called index circle, and pointed out that the focal depth is the product of the radius on the index circle multiplied by the square root of three.

The Charleston earthquake had two foci. The depth of the Woodstock focus he computed to be twelve miles and of the Rantowles focus nearly eight miles. The determination of the index circle, as Dutton himself recognized, is a matter of difficulty, and the conclusions must be regarded as only approximate.

Concerning the rate of propagation, he remarks (22, page 211):

> "After a careful study of all discussions of this particular problem, based upon the observations made in other earthquakes, I have no hesitation in declaring my opinion that the result from the Charleston earthquake far outweighs them all, and that all preceding determinations of this quantity are wholly invalid or wide of the mark."

The average speed of propagation of the Charleston earthquake Dutton determined from three groups of observations to be 5,184 meters per second. He devoted much consideration to the nature and mechanism of the earthquake wave motion.

After his retirement, with abundant time at his disposal, his active mind was much employed in the further study of volcanoes and earthquakes. His latest publication on the latter subject is a book entitled "Earthquakes in the Light of the New Seismology," a most comprehensive, instructive, and useful contribution to popular knowledge. To quote his own words:

> "Chapter I sets forth the nature of an earthquake according to the modern concepts. It defines the technical terms used in discussion, and describes the action taking place on the surface of the ground during a quake of great energy. Chapter II is a general discussion of the causes of earthquakes. Two causes are recognized, apparently quite distinct, though possibly they may have interrelations not yet recognized. The first cause is volcanic; the second is that force which is presumed to be always active in disturbing the rocks which form the outer shell of the earth, resulting in the building of mountains, the folding and shearing of the strata, and the elevation and depression

of the earth's crust. Thus we have two groups of quakes, volcanic and tectonic. They have in many cases distinct characteristics, and these are described in chapters III and IV."

The more important instruments used in seismometry are described in chapters V and VI, and chapter VII discusses the details of seismic vibratory motion and explains the four kinds of waves with which the inquiry deals.

A chapter (VIII) is given to the amplitude and period of vibration, and two chapters (IX and X) to the subject of intensity. The chapter on the variation of intensity points out the method of computing the depth of origin of an earthquake wherever observations sufficient in number and accuracy can be obtained.

"The speed of propagation of seismic vibrations is then treated (XI and XII). No specific problem in connection with earthquakes has been more diligently investigated, and few are so difficult as this. It is only very recently that definite results upon this question have been reached. The chief trouble has been the great complexity of the waves generated by an earthquake, their different rates of propagation, and the difficulty of separating one kind from another. Nor was is known until recently that some kinds of waves are propagated through the earth-mass, while others go around it.

"Since the speed of propagation depends wholly upon the ratio of elasticity to density, it becomes an index of those properties in the materials which compose the earth's interior. Chapter XIII is given to the discussion of this aspect of the subject."

The subject of earthquake distribution or seismic geography is treated in two chapters (XIV and XV), and the final chapter (XVI) is devoted to seaquakes.

As an observer, Dutton was quick to grasp the comprehensive, though not overlooking details, and in the field gave most of his attention to the greater problems. As he puts it (Sixth Ann. Rept., page 198):

"I am fond of viewing the facts observed in the field in their relation to broader and more general facts, and of marshaling them into their proper places."

His method of work in preparing his reports was determined largely by his strong imagination. He made but little use of field notes excepting for figures. Shutting out all other matters from his mind, even to the neglect of personal correspondence, and without preparing a written plan or preliminary draft, he read much and discussed with his colleagues. He held the subject wholly in mind until his problems were solved and results fully attained before beginning to write; but when ready he penned all his own manuscripts rapidly under the stimulus of an enthusiasm begotten by a consciousness of his comprehensive and complete knowledge of the subject.

Macaulay was his favorite author, and doubtless had much influence in forming Dutton's style, which is perhaps best exemplified in his "Tertiary History of the Grand Canyon District," where he remarks (page viii):

> "I have in many places departed from the severe ascetic style which has become conventional in scientific monographs. Perhaps no apology is called for. Under ordinary circumstances the ascetic discipline is necessary. Give the imagination an inch and it is apt to take an ell, and the fundamental requirement of scientific method—accuracy of statement—is imperiled. But in the Grand Canyon district there is no such danger. The stimulants which are demoralizing elsewhere are necessary here to exalt the mind sufficiently to comprehend the sublimity of the subjects. Their sublimity has in fact been hitherto underrated. Great as is the fame of the Grand Canyon of the Colorado, the half remains untold."

For years he smoked vigorously at his work, but in later life he desisted. At one time he became greatly interested in the matter of stamps and was employed by the Government to make its Centennial stamp collection.

He gave much attention to the Far Eastern question, and for amusement during the leisure hours of later years he wrote a book on China, but it did not reach publication.

His mind, well filled with readily available knowledge on many subjects, gave him unusual power as a conversationalist, and he was fond of discussion, especially with his compeers, G. K. Gilbert and W. J. Powell, the other members of a devoted trio, of whom in acknowledgment he generously remarked, "If I paid them their intellectual dues I would be bankrupt."

Though somewhat austere, Dutton had many friends. He was a kind, lovable, generous man, with high ideals and an intense hatred of shams. His last message was: "Farewell to my old friends on the Geological Survey."

It is said "he knew the end was at hand, and he met it calmly like the philosopher he was. Apparently he just fell asleep."

He died January 4, 1912, of arterio-sclerosis, at the home of his son, in Englewood, New Jersey. His wife, Emeline C. Dutton, still resides at the same place, but his son, Clarence E. Dutton, is now at Edgartown, Massachusetts.

Major Dutton was a member of many scientific and other organizations, among which may be mentioned the Philosophical Society of Washington, the American Geographical Society, the Academy of Political and Social Science, the Geological Society of America, the Seismological Society of America, and the National Academy of Sciences.

In his writings Major Dutton had a most vigorous and impressive style. His choice of words is of the best—euphonious, simple, but full of force and interest. His phraseology is direct, winning the attention of the reader and holding it throughout. He may be justly considered one of the best writers of popular geological science of his day.

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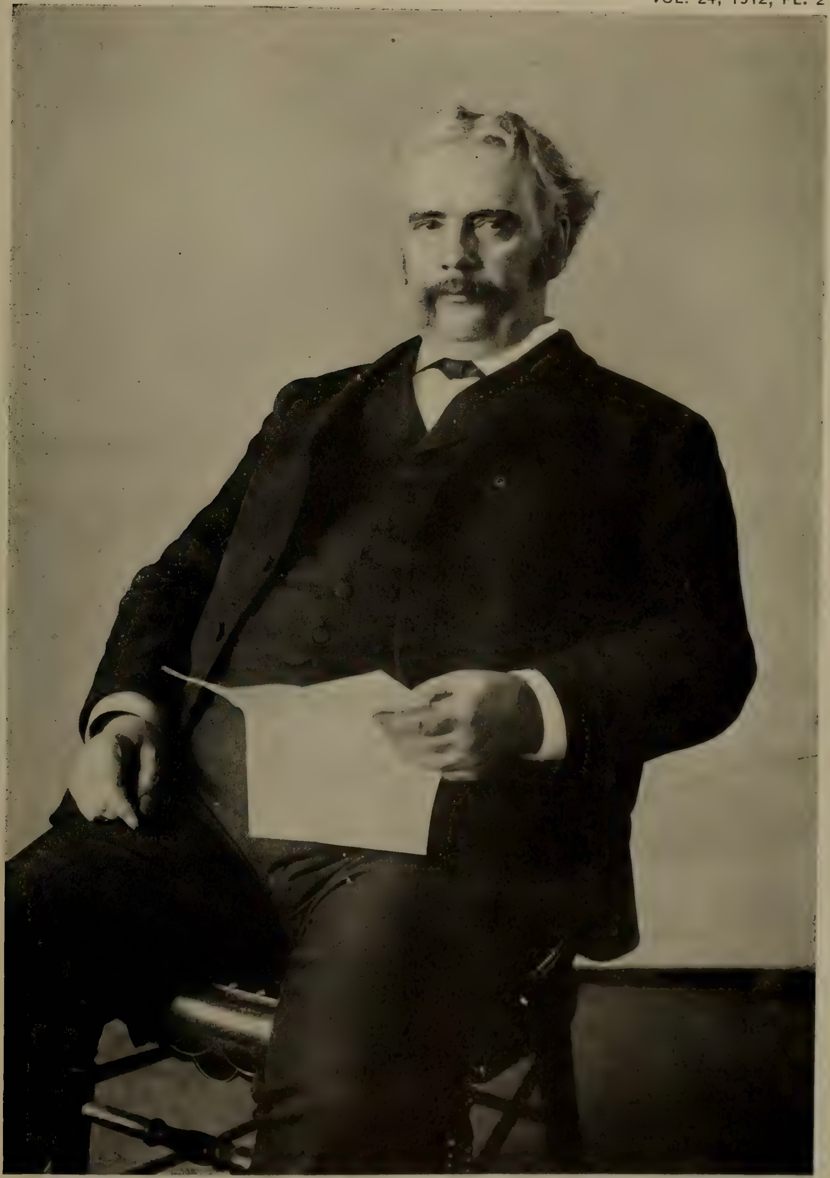
MEMOIR OF W J MC GEE

BY F. H. KNOWLTON

In these days of advanced specialization and refinement in the study of scientific problems, it has seemingly become increasingly evident that the best measure of success can only be attained with the full panoply of a modern educational equipment. Yet there have been in the past, and doubtless there will be in the future, notable exceptions to this rule. It is often said of one who has reached an eminence without the stimulating aid of early educational advantage, that had he fortunately possessed this training no one may measure the higher eminences to which he might have ascended. Rather is it possible—indeed, probable—that the spark of genius is stimulated by adversity, and that breadth of vision and strength of character come oftener as the fruit of action rather than of ease; for

> "So doth luxury make weaklings of us all."

Certain it is that Doctor McGee attained a very notable measure of success with the minimum of formal educational training.



WJ McGee

William John McGee—or simply W J McGee, as in later years he preferred to be known—was born on a farm at Farley, Dubuque County, Iowa, April 17, 1853, and died at Washington, D. C., September 5, 1912. He was the fourth of a family of eight children born to James and Martha Ann (Anderson) McGee, and is survived by three brothers and a sister, the others having died in infancy or youth. His parents were of sturdy Scotch-Irish stock, his great-great-grandfather on the paternal side having been Alexander McGee of County Down, Ireland, who came early to this country, and on the maternal side the line leads back to Samuel Anderson, who was born at sea, about 1740, of Irish emigrant parents. The latter resided near Yorktown, Virginia, and both participated in the Revolution on the American side, which perhaps accounts in a way for McGee's intense Americanism. In infancy and early youth, although always of large size for the years, McGee was in frail health and somewhat uncertain in disposition, and even in later life, notwithstanding his rugged physical appearance, he was far from being as strong as seemed apparent.

McGee's early education followed the usual course in sparsely settled county districts. He attended irregularly the county district school until he was about 14 years of age, but as the school was confessedly of low grade, it is not probable that he advanced much beyond the merest rudiments. From this time on his education was almost entirely the result of intense individual effort. In this, as is so often the case, he was urged and stimulated by the mother, an excellently well informed woman, who was particularly anxious that her family should be well educated. The last one apparently to give him formal instruction (1867-1868) was an older brother, who speaks of him as an exceedingly apt pupil, acquiring knowledge easily and retaining it in what was later developed into a really marvelous memory. His home studies were continued over the years 1867-1874, during which time he studied Latin, German (in which he became especially proficient), and the higher mathematics, including astronomy and surveying. He also read law and to some extent engaged in justice-court practice, but this never was considered as of much importance in his plan of life and was soon laid aside. He was, however, an excellent surveyor, having been instructed in this field by a maternal uncle, and his work was much in demand in the neighborhood.

When about twenty years old McGee learned blacksmithing and for several years engaged in the manufacture and sale of agricultural implements. In conjunction with an older brother and a cousin, he invented and patented (June 9, 1874) an improved adjustable cultivator, but the enterprise was not financially successful, nor was the invention a pioneer in its class.

It was apparently about this time (1874) that McGee's attention was first directed to geology. Just what the incident was that first claimed his attention and stimulated his interest in what was later to be one of the dominating activities of his life is not known. The glacial mantle which so completely covers northeastern Iowa offered many then unsolved problems, and together with his brothers he explored with keen interest the numerous caves about their home and studied the peculiar rocky topography with more than boyish interest. He read widely of such books and papers as were then available on glaciation and its phenomena, and began independent observations which soon brought him into communication and contact with other workers in this field. The fact that he joined the American Association for the Advancement of Science in 1878 (27th meeting, St. Louis, August, 1878), enrolling himself in the section of geology, shows that his interest was even then crystallizing along these lines. So far as learned, his first scientific paper, "On the relative position of the forest bed and associated formations in northeastern Iowa," was published in 1878 and was the forerunner of many of like import. Between the years 1877 and 1881 he prosecuted, as a private enterprise, a topographic and geologic survey of some 12,000 square miles of territory in northeastern Iowa, though the full results were not published until 1891.

McGee's first work under Federal auspices was a report on the building stones of Iowa, prepared for the Tenth Census of 1880, though not published until four years later. This, but more especially his careful work on the multifarious phenomena of glaciation in the upper Mississippi Valley, had attracted wider attention, and in July, 1883, he was called to the U. S. Geological Survey, then under the directorship of Major J. W. Powell. In a very short time he was placed in charge of the division of Atlantic Coastal Plain geology. Although then but thirty years of age, he came, not as a mere tyro or dabbler in geology, as might be presumed from his previous isolation, but with an astonishing breadth of view and maturity of judgment, and within the next ten years he erected a foundation which must always be considered by any who would study the geology of the Coastal Plain. This decade—1883-1894—covers the period of his most intensive, constructive geological activities. He resigned from the Geological Survey on June 30, 1893, to assume on the following day the position of ethnologist in the Bureau of American Ethnology, to which department he had accompanied Major Powell. One year later he became ethnologist in charge of the Bureau, and continued in this position until July 31, 1903, when he resigned to assume charge of the Department of Anthropology of the St. Louis Exposition, where he brought together an unprecedented assemblage of the world's peoples. At the close of the exposition he became the first director of the St. Louis Public Museum, continuing in this position from 1905 to 1907. On March 14, 1907, President Roosevelt created an Inland Waterways Commission, and at the first meeting of this Commission Doctor McGee was elected vice-chairman and secretary, a position he continued to fill until his death. About the same time (March 23, 1907) he was appointed as an expert in soil waters in the Bureau of Soils, U. S. Department of Agriculture, and in this position he also continued until his death.

Aside from the honors and responsibilities which came with a busy official life, many additional honors were conferred upon Doctor McGee. He was one of the principal founders of the Columbia Historical Society; sometime president of the American Anthropological Association, the Anthropological Society of Washington, the National Geographic Society, and the American Association for the Advancement of Science (1897). He was the senior speaker in the department of anthropology at the World's Congress of Arts and Sciences in 1904, and non-resident lecturer on anthropology at the State University of Iowa. In 1901, in recognition of his distinguished attainments, the degree of LL. D. was conferred on him by Cornell College, Iowa, at which time he presented a comprehensive essay on the "Beginnings of mathematics."

In 1888 Doctor McGee was married to Anita Newcomb, who, with a son and daughter, survives him.

In the field of the Pleistocene geology of the upper Mississippi Valley McGee was really a pioneer. At the time he began his studies very little was known of the glacial history of this region, and he did much to establish a knowledge of the succession of invasions and recessions of the ice-sheet, and while many of his conclusions have been subject to revision in the light of fuller modern investigation, much of his work remains, and must remain, as a basis on which subsequent knowledge is to be builded.

McGee's most notable contributions to American geology are, of course, in the Atlantic Coastal Plain. In this field there must ever be associated the names of four notable students—Hilgard, Smith, Dall, and McGee. These men have laid the foundation, however much it has been, or in future will be, modified, upon which all subsequent work must be erected. In the particular phase of the subject which McGee made his own he was again a pioneer. He saw and appreciated the broad problems of stratigraphic continuity and succession, of continental elevation and depression, and he set about their solution. His work was distinctly constructive, and as such finds a permanent place in American geologic history. While certain of his conclusions, as is almost inevitable in pioneer work, have been modified or revised, the broad, fundamental generalizations remain as an essential basis for later students.

After an interval of a dozen years or more following the close of his studies on Coastal Plain geology, during which his attention was mainly occupied in the field of ethnology, Doctor McGee again returned to the consideration of certain collateral geologic problems. It had come to be the fancy in certain quarters that the removal of the forest or vegetal covering had little or no influence on the run-off of surface waters. His report on "Soil Erosion," published as a bulletin of the Bureau of Soils in the United States Department of Agriculture, is a complete and graphic refutation—if such were really needed—of this contention. His last work, completed less than a month before his death, and also to be published as a bulletin of the Bureau of Soils, is an elaborate study of subsoil water and its essential relation to agriculture.

Of his anthropological and ethnological work only the briefest mention may be made here. While much of his time was given to administrative work, he nevertheless found opportunity for a number of studies, perhaps the most notable being a study of the Seri Indians, a fierce, previously unstudied tribe inhabiting certain islands off the coast of Lower California.

Doctor McGee did much for the Geological Society of America. He was one of its founders and served for four years as its editor, establishing the BULLETIN, its official publication, on the high plane it then and has since maintained. His constant attendance at the meetings during the earlier years of the Society's existence will be recalled, as well as his contributions to many notable discussions of geologic problems.

W J McGee was a man of commanding presence, one who would attract attention in whatever assemblage he might find himself. Although seemingly somewhat formal in address to those not intimately acquainted with him, he was, nevertheless, a man of cordial, sympathetic manner and of deep human sympathies. It is related of him that once, when in attendance on a meeting of the American Association, he was asked by a local divine to fill his pulpit at the Sunday evening service. Although not affiliated with any church, McGee accepted at once, and, selecting as his text the words "Love ye one another," delivered an address replete with human sympathy and understanding. He was kindly and considerate to those who worked with him and generous to a degree, it being rare indeed—too rarely for his own best interest—that an appeal was without substantial reward. He was a good conversationalist and a ready public speaker, having at command a splendid memory and a really wonderful vocabulary; in fact, in the use of the latter he sometimes seemed to border on the pedantic, yet when a new or unfamiliar word was used it was usually found in last analysis that it was a fitting word for the shade of meaning desired to be conveyed.

McGee was a helpful man, ever ready with counsel and information to assist whomsoever might come to him. To the younger men he was especially considerate and helpful, drawing freely upon his vast storehouse of information without thought or regard for personal credit. When the so-called conservation movement was launched a few years ago, the exigencies of public life made it impossible for full credit to be given to all who had a guiding hand in the work, but from one in position to know it appears that the success of this movement was in large measure due to the far-sighted, comprehensive policy and sterling advice of Doctor McGee. Many of the activities of the Inland Waterways Commission, of which, as already mentioned, he was the Vice-Chairman and Secretary, were due to his energy and initiative. Laborious statistical tables were compiled and scattered information brought together in usable form. During all these later years, although not engaged in active geological investigation, he was always willing and anxious to discuss the newer results in the several fields and to accept without question or resentment those which offered a surer solution than any he had himself proposed.

Although it is said of Doctor McGee that in early life he was distinctly averse to manual labor, in later life he certainly developed untiring energy, as a glance at his many and varied accomplishments will show. He was also a good organizer and was systematic and painstaking in all he undertook. His last work on "Wells and Subsoil Water," the proof-sheets of which lie before me, was recalled during the last weeks of his illness and was finally submitted, but two weeks before his death, complete to the last detail.

It is perhaps fitting in this connection that a word should be said of the remarkable courage and fortitude exhibited by Doctor McGee during the progress and culmination of the insidious malady (cancer) which caused his death. For the benefit of humanity he made a special study of his own case, setting down calmly and imperturbably the progress of the disease from its first observed inception, in 1894, to its obvious dominance, in April, 1912, this diagnosis being published a few days after his death (*Science*, September 13, 1912). It thus appears that for the last fifteen years of his life his work—some of it the most exacting of his career—was carried on in the impending shadow of certain dissolution, much of it at the last under the stress of acute physical suffering, but there was no slighting, no faltering, no repining.

As showing his abiding devotion to the cause of science and the public good, the following paragraph may be quoted from his will:

> "Pursuant to an intention fixed in early manhood on learning that a certain State provided by law that medical graduates should have had dissecting-room experience, and yet made no provision for the requisite subjects; and conformably with the shocking economic waste represented by the cities of the dead in the long settled portions of the country; and in accordance with my custom of devoting my efforts and myself to the public good, I give and bequeath my body for purposes of dissection to any medical college selected by my executor."

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Very sincerely yours

R. S. Tarr

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MEMOIR OF RALPH STOCKMAN TARR

BY J. B. WOODWORTH

Prof. Ralph Stockman Tarr was born in Gloucester, Massachusetts, January 15, 1864, the son of Silas Tarr, a contractor, and his wife, Abigail Tarr, née Saunders. He died suddenly, March 21, 1912, at Ithaca, New York, where his grave may be seen.

Tarr's boyhood was spent in Gloucester and about Cape Ann, the most typical portion of the New England rock-bound coast, environed with granite quarries ashore and a seaport teeming with marine life. By this environment and a readily understood chain of human influences, the chief links in which were Hyatt and Shaler, Tarr was led along with ever-increasing enthusiasm into the life-path of the naturalist.

The youth whose life we are to sketch went through the public schools of his native town, graduating from the local high school in 1881. In the summer of that year he entered the school of zoology, held at Salem, and in the following autumn was enrolled at Harvard University as a special student in the Lawrence Scientific School, evidently with the intention of becoming a zoologist. In 1882 he returned to Annisquam, near Gloucester, to act as an assistant to Professor Hyatt in the zoological laboratory at that place, in connection with which institution he for about two years was engaged principally in collecting and dredging marine animals in Ipswich Bay. During this time, in 1883, he joined the U. S. Fish Commission, under Dr. Spencer F. Baird, and took part in deep-sea exploration south of New England on the steamers *Fishhawk* and *Albatross*. In the winter of 1884 he was an assistant in the division of invertebrate zoology of the U. S. National Museum in Washington. In a complete bibliography of his writings there will be found lists of zoölogical specimens published at this time, as well as articles of a scientific character furnished to the public press.

Hyatt had apparently so far been the chief counselor of Tarr, the student of zoology. At Harvard Tarr had met Shaler.[1] In the fall of 1888 Tarr returned to Harvard and began the study of geology under Shaler, of physical geography under Davis, and later of petrography under Wolff, with lectures on economic geology by J. D. Whitney.

At Harvard Tarr was perhaps the most brilliant and versatile member of a group of students drawn to the department of geology by the unique personality of Shaler. Penrose was about completing his academic studies when Tarr came. The group to which Tarr attached himself comprised Charles Livy Whittle, who shared his college room in Holyoke, 14, later a member of the U. S. Geological Survey, and now a mining geologist of Boston; Collier Cobb, now professor of geology at the University of North Carolina; Dr. George Edgar Ladd, sometime director of the Rolla School of Mines; Dr. August F. Foerste, a Fellow of this Society; Prof. R. E. Dodge, and the writer. There were other associates outside of the geological circle. Some of those inside this circle knew him before I made his acquaintance and were his intimates to a greater degree. To me Tarr was the most interesting, congenial, and sympathetic of my college friends. He invited me to his parents' home at Gloucester, and between us there sprang up a friendship based upon good-will and an interest in our common subject of study that led when Tarr left Cambridge to a correspondence which for years on his part constitutes so faithful an account of life as a geologist and college professor that it seems appropriate in this memorial to allow abstracts from his letters to tell that story of his noble persistence and fruitful endeavor.

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[1] Tarr spent the academic years 1881-1882, 1884-1885, 1886-1889, 1890 1892 at Harvard.

In what follows I shall draw largely from these sources, which form for more than a decade a record of his activities.

Tarr's first geological field work was done on Cape Ann under Shaler's direction. In Shaler's Report on the Geology of Cape Ann he states "by far the larger part of the field observations embodied in this memoir have been made by my assistant, Mr. Ralph S. Tarr."[2]

Upon the organization of the arid land work of the U. S. Geological Survey, under Newell, Tarr left college to spend the government year 1887-1888 in that service. Following this experience he acted as assistant geologist, under Dumble, on the Geological Survey of Texas in 1889-1890. From San Saba, Texas, he wrote, December 25, 1889:

> ". . . I am hustling things as fast as I can, for I want to make every moment count."

In the summer of 1890 Tarr was back in New England, assisting Shaler in mapping the glacial deposits of Massachusetts and Connecticut for the U. S. Geological Survey. He was elected a Fellow of the Geological Society of America in August of that year.

That fall he reentered the Lawrence Scientific School to complete the work for the bachelor's degree, graduating with the class of 1891. During the academic year he also acted as assistant in geology in the laboratories.

In the summer of 1891 he was engaged as Professor Wolff's assistant on the U. S. Geological Survey in the highlands of New Jersey. On July 18 he wrote from Andover, New Jersey:

> "My work is getting along swimmingly, if by that you mean I am entirely at sea! . . . The only way is to plug ahead blindly with the areal work, putting down and plotting every observation and examining all the ground. The problems suggest themselves, then, and then comes the solution."

Again, on October 14, he wrote:

> ". . . Foerste[3] is in the vicinity knocking out fossils. He has found fossils in three of my localities. What an eye he has! It almost seems as if he had an extra sense entirely lacking in me."

Still later, November 29, he says:

> "Since returning I have been plugging away and making little progress, though I believe I am on the track of some interesting things. Still this may be the same old will-o'-the-wisp which has been leading me on all summer. Time and time again I have been almost persuaded that I had the matter in hand to find a thing which disproved it all." . . .

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[2] Report of the Director of the U. S. Geological Survey for 1888-1889, p. 537.

[3] Dr. August F. Foerste, F. G. S. A., then assistant, U. S. Geological Survey.

Tarr was appointed assistant professor of dynamic geology and physical geography at Cornell University early in 1892 for the remainder of the year. On February 9 he wrote:

> "Everything is very pleasant here. I have never felt so thoroughly contented before. There is plenty to do without that infernal feeling of rush which hangs in the Cambridge atmosphere. I plug ahead, doing a good, solid day's work, but do not keep it up till midnight."

His first geological papers now made their appearance, and he notes the satisfaction he felt in the reception of his rift paper by petrographers, his Permian paper by Mesozoic paleontologists, and his Massachusetts moraine paper by glacialists. Kind-hearted Russell sent him in exchange all of his publications on Mount St. Elias, "which are, as you of course know," says Tarr, "the most remarkable glacial publications of the decade." This appreciation of kindnesses shown him was a strong trait in Tarr's communications, both spoken and written.

The year 1892 was a troublesome one for Government geologists.

Tarr was married in March, and early in the summer took again to the field in New Jersey to continue the work on the crystalline rocks of the highlands. In midsummer came the notice that the Geological Survey had failed to obtain the expected appropriation from Congress. Entire parties of men in the field were left to their own devices. On August 6 Tarr wrote from Gloucester:

> "Just a word to let you know where the cyclone has landed me. . . . It has left me high and dry, so far as I can see. I hear no word from either Madison or Ithaca, and have little hope of either place, though, of course, there is still a chance. If nothing turns up I shall be in Cambridge during the winter and will try for a higher degree."

By the 25th of August the sky had cleared, and he knew that he was going back to Ithaca for another year. On returning to Cornell there were collections to put into shape and the usual routine of college work. The academic year was one of hard work, not without apprehension concerning the future. On the 18th of May, 1893, he wrote:

> "I still have to teach a wide range of subjects, but am gradually turning them off. Whenever the department is settled there will be a differentiation, and I will be able to discard petrography and economic geology."

The stoppage of the Geological Survey work in New Jersey left Tarr, in the summer of 1893, to employ his vacation to the best of his ability. He went to Gloucester, but was by no means idle. Few of his friends heard from him during the summer. On September 23 he wrote from Ithaca:

"I was very busy all summer and kept myself pretty close to my temporary study. I came here September 1 and am again well in the harness. . . . I must apologize for my silence this summer, but I got my nose down to the grindstone and could not get it away."

On October 1 Tarr gave an explanation of his unusual silence:

"I have put in eight solid hours a day, and as a result I have finished a text-book on economic geology, and yesterday sent the manuscript and illustrations complete to the publisher. It was my plan to do a little field work near Gloucester, do a good deal of much needed reading, and prepare a syllabus on economic geology for use in my class in the spring term, for, as you no doubt know, there is no suitable text-book on the subject. I soon found that the syllabus would require as much time as a text-book, very nearly, and the idea dawned on me that I might as well do the latter; so off came my coat, and between July and October I wrote 1,000 pages of manuscript, blue-book size, and then rewrote it, besides preparing about thirty illustrations. I had the subject fairly well in hand and had complete notes and a fairly good library, otherwise I could not have done it."

This letter affords an authoritative explanation of the writing of the Economic Geology. Older and then more experienced geologists, perhaps from modesty, perhaps from temerity, had refrained from preparing a work such as Tarr needed. The small hand-book by Dr. S. G. Williams,[4] his predecessor at Cornell, in the teaching of economic geology was out of date, if not out of print. There was a demand for a book on the subject. Tarr took the bull by the horns, and without saying a word to any one produced his book, and ran the gauntlet of reviews which followed. The experience was instructive. In it Tarr measured his powers for the writing of books. He learned that the writer of geological pamphlets, such as he had so far been, was regarded by his fellow-craftsmen as doing the normal expectable thing and worthy of all praise, and that the author of a book addressed ostensibly to those outside of the profession, though about to enter it, is regarded with jealous solicitude by friends, acquaintances, and strangers who may or may not have made similar ventures in the domain of authorship lying beyond the borders of the pamphleteer. Whether or not it was a wise move to have written this book, Tarr showed by doing it his indomitable industry and courage. The experience prepared him for the work which he was later to undertake in the field of physical geography.

The summer of 1903 was devoted to field-work about Cornell University.

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[4] Samuel G. Williams: Applied geology. New York: D. Appleton & Co., 1886, pp. xii, 386.

On August 23 he wrote:

> "I am doing the glacial geology of the Ithaca folio and am getting some fine things. Wish you could come out here and see some of them."

This intense intellectual interest in the field upon which he was at work was a striking characteristic of Tarr's mind. He saw much wherever he went, and invariably sought to share his delight in his observations with others.

The autumn of 1893 saw him teaching at Cornell, busy with the proof-reading of his book, and working on the pegmatites of the New Jersey highlands. In December he attended the Boston meeting of the Geological Society to read his paper on "Lake Cayuga: A rock basin," as he remarked in a letter dated December 3, "the title explaining the conclusion." He adds:

> "My book progresses and all the proof is read. I am now on the index, a most distressing job. A week more and the thing is done; then I am going to take up and try to finish my New Jersey material. I have a number of good things there, but have hardly had the time to even consider them."

January 7, 1894, he wrote about the appearance of the text-book of Economic Geology:

> "Naturally I feel a trifle anxious just now as to the way my book will be received. . . . I have chosen my bed and must lie in it."

Tarr was now well known to the geologists of his own country. In March, 1894, he was approached with regard to a place on the editorial board of *The American Geologist*, an offer which he concluded not to accept. In November of that year he began to feel the effects of overwork, which was the greater by reason of teaching in the summer school at Cornell. This tired feeling followed him during the academic year.

On July 11, 1895, he wrote:

> "I was so badly knocked down in June that I left before commencement for three weeks in the field, studying the Erie shore in western New York. . . . I have returned quite refreshed and am now in summer-school work, with a small class of seven. In my spare time I am working on my physical geography and getting in shape a physical geography laboratory, for which I have been given an appropriation of $2,000."

The Economic Geology had begun to yield returns, and, as we note, Tarr had laid his plans for further efforts in the line of text-books. It was his hope that after a few years his writings would put him in a position to be able to undertake independent investigations in the field, at which time he proposed to devote himself mainly to field-work. The sequel shows how he accomplished his purpose. His letters breathe this spirit of independence and determination.

On February 10, 1895, he wrote about the drift into writing text-books:

> "I do not know what I am coming to. Everything points to the fate of a writer of books, great and small. I had promised myself a summer of field work, but it now looks as if it would not materialize. A chance to write three books has come to me in the past two months. . . . I have been at work on for five years . . . two books on physical geography." . . .

In February, 1893, he complained of the effects of confinement to work. His campaign for the spring and summer was laid out. "I am going off," he states, "to the Bermudas for the spring vacation to recruit and to see something of midoceanic coral life. In the summer I am going to put in three months in Newfoundland, on the shores and in the interior." His paper on the Bermuda Islands was the fruit of the first trip; but the opportunity to accompany Peary to Greenland for the summer led to the abandonment of the Newfoundland excursion. On returning from this expedition, Tarr wrote, October 31:

> "My trip to Greenland was full of wonders and replete with results. . . . I think that the most important result of the trip was the proof that in the part of Greenland which I saw the ice-sheet had submerged all the land, even the highest. . . . I do not think that a geologist, and especially one working in the glacial aspects of the subject, can afford to miss the opportunity of spending a summer in the north and a month with the great glacier."

The Cornell expedition to Greenland which Tarr at this time led gave him the long-desired opportunity to study glaciers at first hand. His studies of the Cornell glacier were presented before the Society at the meeting in 1896.

In the winter of 1897-1898 the question of the origin of peneplains occupied his attention. On February 12, 1898, Tarr wrote:

> "Lack of confidence is not one of my failings, but there is a matter, these five years on my mind, upon which I sometimes question my own powers. Do you know that I am a disbeliever in peneplains? Several years ago I wrote an article opposing the theory, but took alarm when I saw every one else believing in them. I pigeonholed the paper. I rewrote it. . . . Again I put it away. Now I have it out again, rewritten. I believe it is right, yet I can not help doubting it, for I seem to have no companions."

The paper eventually appeared that year. His doubts appear to have arisen from a failure to find that degree of peneplanation which he expected to see in New England and parts of New Jersey.

The years 1898-1899 saw the completion of two of his home geographies, with the collaboration of Prof. Frank Morton McMurry, of Teachers' College, New York city. In the summer of 1900 he was plunged into grief by the sudden death of his infant son Shaler, named after his friend and preceptor, Professor Shaler.

The academic year 1901-1902 was spent in Europe on sabbatical leave. The summer of 1901 was spent in Switzerland. He was back in this country at Christmas to look after the publication of his geographies. On January 7, 1902, he wrote from Ithaca:

> "I have my passage engaged for the 30th of January. I go directly to Italy, where I shall stay till May, then go slowly northward, putting next summer in the British Isles."

During the winter of 1902-1903 he prepared the Cape Ann shoreline paper. In the summer of 1903 he was again at work on the glacial geology of the Ithaca folio for the U. S. Geological Survey.

In the spring of 1906 Tarr was made head of an independent department of physical geography. He was now full professor of physical geography and at the height of his powers.

The summer of 1906 was again spent in Alaska. On the 15th of October he wrote from Ithaca:

> "You will be interested to know that since last summer the Malaspina glacier has started a forward movement, which has so crevassed it that it is no longer available as a highway of travel. This is true, also, of a number of smaller glaciers in the bay, but not of all. Earthquake effect?"

This suggestion of earthquake action grew later to form his theory of acceleration under seismic motion, a real contribution to glacier physics.

In the summer of 1909, conjointly with Prof. Lawrence Martin, Tarr conducted to Alaska the first expedition of the National Geographic Society, his second and last being that of 1911. In October, 1909, he sailed for Europe, spending the winter mainly in Berlin with Penck. In the summer of 1910 he attended the Geological Congress at Stockholm, and was a member of the party to visit Spitzbergen, an opportunity which he gladly embraced as a supplement to his studies of glaciers in Greenland and Alaska.

On returning to Cornell in the fall of 1911 he became charged with the Cornell seismographic station and was about to enter the small list of workers in this adjunct to geology when all his work was cut off.

From this view of the life of Professor Tarr, seen at close range from the predetermined vantage point of a college-mate, let us now step back in order to take in perspective a wider survey of his professional career.

Tarr's field-work was done at widely separated points on the North American continent. He worked in Massachusetts on the geology of Cape Ann; he helped to unravel the structure of the Gay Head cliffs on the island of Marthas Vineyard—a locality made classic by the earlier labors of Edward Hitchcock and Sir Charles Lyell; he made glacial maps of parts of that State and Connecticut, as well as of New York; he carried his studies of glacial erosion on at Mount Katahdin, Maine, and in the Finger Lake region; he did areal work in Texas and the highlands of New Jersey, and made geological and physiographic observations in New Mexico and Montana, on the Bermuda Islands and in Cape Breton, and finally he left his name indelibly associated with the pioneers of the scientific exploration of Greenland and Alaska.

It was not his privilege to devote his life to the painstaking decipherment of the geological structure and form of a single natural province of the continent. The sporadic character of his early work, both as to locality and subject-matter, was under the control of the inexorable law of necessity, tempered by favoring opportunity. Tarr came into geology at the time of the birth of the daughter science of physiography. As a student of Davis, it was natural that he should enter the new field. If the orthodox geologist at times complains of the numerous breaks in the ranks of the old school on the part of those who have been trained in its methods only to betake themselves to the once despised superficial geology, it must now be borne in mind that a knowledge of existing causes is the key to the past, that the study of peneplains has thrown most important light on unconformities, and that the study of glacial deposits has elucidated the nature of tillite and led to the recognition of the falsity of the doctrine of a globe gradually declining in temperature from Cambrian times to our own. Tarr's varied training in zoology, geology, petrography, and physiography gave him a broad insight into the problems of the new field of research.

Of his contributions to geology proper we have the phenomenon of rift in granite, which appears to be new to the science. His descriptions of the dislocation which gave rise to the Alaskan earthquake of 1899 is a most important addition to our knowledge of the relation of earthquakes and faults, with accompanying changes of level of the land in relation to the sea. His recognition of earthquake shocks as a factor in glacial motion is an important and helpful contribution to our knowledge of the causes which affect the mysterious advances and recessions of glaciers, one which promises, when fully elaborated, to throw yet further light on the physics of the globe. His studies of glacial erosion in the regions of acting and vanished glaciers include such discoveries as the hanging valley, through glaciers; in river work, potomography—to use the forgotten terminology of Edward Hitchcock—Tarr called attention to extended rivers and anastomosing streams.

Tarr's glacial work began under Shaler in the classification and mapping of the moraines of southern New England long before he had ever seen a glacier and at a time when the stratified drift was still known as modified drift, implying that in origin the gravels and sands were later in origin than the boulder-clay and till. The problems which arose at that time in Tarr's mind in the attempt to imagine the relations of eskers, kames, and kettle-holes to the vanished ice-sheet found partial and in some cases complete explanation in the phenomena of the existing ice-fields of Alaska. Tarr's illustrations of kettle-holes in the outwash plains of Alaska are the best illustrations we have. Although it is true that the diagnosis of these ancient glacial deposits of middle latitudes had been correctly made by those who may never have seen a glacier, Tarr's illustrations and descriptions came as a welcome confirmation of deductions made in a science which professes to proceed from the observation of existing causes to the interpretation of past effects. That the deductions were correctly drawn is due to the sufficiency of the glacial theory to explain more than its founders included in its original application.

Tarr wrote readily. He had the faculty of putting on paper his thoughts at top speed, and it is this element in his style which gave his writings the power which few text-books ever possess. It is said that when his Physical Geography came out and was introduced into the schools, that the parents of those pupils who had the book took it up and read it! If in the first edition of a work there were slips of language or transpositions of the viewpoint, as when in writing in Ithaca his thought was projected northwestward to the site of the north magnetic pole, leading him to write of that geographic point as southwest of the North Pole, the misstatement was obvious and readily corrected. The wonder is that in writing so much he made so few mistakes.

His writings display a steady growth from small beginnings in the published lists of a collecting naturalist to the monograph on the Alaskan earthquake of 1899. His Alaskan work properly crowns his labors in physical geography and geology. It was done in the prime of life, and not only in quantity, but in quality, it must be admitted to take a high rank among the contributions to North American geology and physical geography.

Turning now to Tarr the Cornell professor, we find him an inspiring instructor and leader of young men. Of his students who have followed in his footsteps there are to be named R. H. Whitbeck, of the University of Wisconsin; Frank Carney, of Denison University; John L. Rich, of the University of Illinois; O. D. von Engeln, of Cornell University; F. V. Emerson, of the University of Missouri; G. D. Hubbard, of Oberlin College; G. T. Surface, of Yale University; F. S. Mills, of St. Lawrence University; Lawrence Martin, of the University of Wisconsin, his brother-in-law and associate in his Alaskan work; his younger brother, Raymond P. Tarr, now a mining geologist. Marvin, the companion of Peary, who lost his life on the memorable polar expedition, was working on a doctor's thesis in glacial geology under Tarr's supervision.

With all students he was on cordial terms and his house was open to them. On Sunday evenings the homesick college student found there the entertainment, social and substantial, that cheers; for Tarr knew that the college boy has not only a brain, but a stomach, which calls for refreshment. As a faculty member he took a lively interest in his college and in the development of his department.

As a lecturer he spoke without manuscript, but had carefully prepared notes. These were printed for the use of students. One of his students speaks of him as possessing a personal charm of presentation which inspired and induced hard work in his students.

In the field he is said to have been even-tempered, brave, running risks to get data, but sensible and moderately cautious. In Alaska his life was in serious danger three times—twice in glacial streams and once from a bear—but he regarded these adventures as part of the day's work. Modest and generous, he felt keenly both appreciation and depreciation of himself and his work; a man with a purpose in life; strong in the elements of human character; and if at times he made what seemed to him enemies, he made and retained friends.

In his chosen field of physical geography he attained a high rank. His fellows honored him with the presidency of their Society, a post which he held at the time of his death. Gilbert,[5] whose work and opinion he valued highly, in a note appended to the paper on Earthquakes of Yakutat Bay, which went to press after his death, paid him the tribute which was his due in saying:

> "His biography when written will be a record of distinguished achievement in physical geography. The present volume testifies to his high rank as an investigator, and his success was equally marked as a teacher and as an author of text-books."

He was associate editor of the Bulletin of the American Geographical Society and of the Journal of Geography. He was a Fellow of this

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[5] Professional Paper 69, U. S. Geological Survey, 1912, p. 10.

Society, of the American Association for the Advancement of Science, and of the Association of American Geographers. He was a member of the Boston Society of Natural History, of the National Geographic Society, the Seismological Society of America, the Sigma Xi, the National Educational Association, and the New York State Teachers' Association; Foreign Correspondent of the Geological Society of London, the Geographical Society of Vienna, and Corresponding Member of the International Commission on Glaciers.

Professor Tarr was married to Miss Kate Story, of Gloucester, March 28, 1892. A son, Russell Tarr, a daughter, and Mrs. Tarr survive him.

Paraphrasing now the colloquial declaration of the young geologist not yet out of college, writing in his camp at San Saba, on Christmas day twenty-three years ago, we may truthfully say of him:

He did with dispatch all he could, and he made every moment count.

The photograph reproduced in plate 3 was taken about 1892 by D. Evans, of Ithaca, New York.

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Professor Tarr contributed articles to Johnson's Encyclopedia, The International Encyclopedia, and the Encyclopedia Britannica (10th edition).

MEMOIR OF ERNEST ROBERTSON BUCKLEY

BY H. A. BUEHLER

Dr. Ernest Robertson Buckley died at Chicago on January 19, 1912, of pneumonia, contracted while examining mining properties in southeast Missouri.

Doctor Buckley was born in Millbury, Massachusetts, September 3, 1872. Three years later his parents moved to Tomah, Wisconsin, in which place he received his early education, graduating from the Tomah High School in 1890. After teaching one year he entered the University of Wisconsin, where he specialized in geology, graduating in 1895 with the degree of Bachelor of Science.

During his university course Doctor Buckley was interested in many of the student activities. He was an exceptionally strong debater, and took part in many of the important intersociety and collegiate debates. To this training may be traced his clear and concise diction and impressive manner of public speaking.

For two years after graduation Doctor Buckley held fellowships in geology at the university, obtaining the degree of Doctor of Philosophy in 1898.

In 1897 he was appointed assistant geologist to the Wisconsin Geological and Natural History Survey, becoming assistant superintendent in charge of geology in 1899. He also served the university for three years as extension lecturer in geology, and in 1901 became instructor in commercial geography.

During this period, although actively engaged in geologic and university work, Doctor Buckley was extremely interested in the civic and political problems of the city of Madison, and for one term represented the university quarter in the city council.

While connected with the Wisconsin Geological Survey he devoted his attention largely to economic problems pertaining to the geology of the non-metallic resources of the State. His first report, entitled "Building and ornamental stones of Wisconsin," stands as one of the first and most complete publications of its kind. The completion of this report in less than eighteen months illustrates the characteristic energy with which he worked and his capacity for rapidly crystallizing field observations for publication. In addition to this volume, he issued reports on the clay resources and highway construction in Wisconsin. A study of the marl deposits of the State was also undertaken, but the results were never published.

E. R. Buckley

The constant relation of glacial phenomena to economic problems in Wisconsin probably aroused a particular interest in the geologic work performed by ice, and he devoted some considerable time during the winter months to a study of the effects of the expansion and contraction of the ice along the shore of the lakes in the vicinity of Madison. The results of these observations were published under the heading "Ice ramparts," by the Wisconsin Academy of Sciences, Arts, and Letters.

In the fall of 1901 he was appointed State Geologist of Missouri and Director of the Missouri Bureau of Geology and Mines, which position he held for seven years, resigning in 1908. Finding the Geological Survey in an utterly disorganized condition, he placed the department on a systematic basis, inaugurating methods for keeping complete records that might be utilized by his successors.

His chief scientific work was completed while acting as State Geologist of Missouri. The importance of the lead and zinc ores of the State and the relative lack of any systematic study covering the genesis of these deposits led him to take up detailed investigations in both the southwest and southeast mining districts.

The report upon the Granby area of southwest Missouri included a theory of genesis applicable to the entire southwest district. As a clear exposition of the genesis and occurrence of the disseminated lead ores, his report upon the deposits of St. Francois and Washington counties is remarkable for its thoroughness. As a result of his observations, Doctor Buckley became a strong advocate of the theory that the lead and zinc deposits of the State were solely the result of concentration caused by descending solutions.

In 1908 he resigned the position of State Geologist to become head of the geological staff of the Federal Lead Company of Flat River, Missouri, being in charge of development and prospecting.

While still serving that company in a consulting capacity, he established an office in Chicago during the fall of 1911.

In 1903 Doctor Buckley was married, in Milwaukee, to Miss Grace E. Magdeburg, who survived him less than a week.

Although extremely busy with his own investigations, Doctor Buckley was ever active in his endeavor to further the interest of science and the mining profession in general.

While investigating the clay deposits of Wisconsin he organized the Wisconsin Clay Workers' Association, a society which has since done much to further the interests of the clay-working industries of the State.

With H. F. Bain, State Geologist of Illinois, he was instrumental in forming the Association of State Geologists of the Mississippi Valley, which later resulted in the larger organization known as the Association of American State Geologists.

Doctor Buckley became the first life member of the American Mining Congress, and took an active part in the incorporation of the organization and in the formulation of plans by which the membership was placed upon a permanent basis. As chairman of the committee on resolutions, second vice-president, and finally president in 1910, he was an important factor in guiding and directing the early work of the Congress.

Doctor Buckley was also a member of the American Institute of Mining Engineers, The Geological Society of America, The American Association for the Advancement of Science, The Mining and Metallurgical Society of America, The International Association for Testing Materials, The Wisconsin Academy of Sciences, Arts, and Letters, The St. Louis Academy of Science, and an honorary member of Tau Beta Pi.

A man of striking personality, Doctor Buckley possessed keen conception, sincere honesty, and high ideals. He expressed himself vigorously and fearlessly, because of which he often gave the impression to comparative strangers of having a brusque nature. To those who knew him intimately was shown the true, sympathetic feeling for those about him and for those in less fortunate circumstances.

While he held an undiminished interest in the advancement of science, his chief activities during the last few years were directed toward the betterment of conditions surrounding the mining industry. His ideas regarding the problems confronting the mining industry are well set forth in the following paragraph, taken from his presidential address to the American Mining Congress in 1910:

> "This association was organized to teach mining men the value of cooperation; that success cannot be measured by another man's failure; that we must have a decent respect for the lives and health of the men that toil beneath the surface; that there must be a willingness to provide adequately for the men and their families who suffer through accident or death; that there should be laws to restrain and punish the man who is in part responsible for the disrespect in which this profession is held, for the fake promoter, who parasites on the public; that all the bureaus of the Federal and State governments engaged in investigations associated with mining are helpful to the industry and deserve our generous and undivided support; that much needful Federal and State legislation, helpful to the mining industry and for the protection of our mineral resources, may be enacted through the united efforts of a representative body of mining men. . . . The interests of the mining industry can not be left in the hands of men who are engaged in agriculture, forestry, manufacturing, transportation, or commerce. They must be cared for by organizations of mining men, and I beseech you, in closing, to contribute to this organization the best that you have in order that it may be a power throughout the land."

The desire to be of service to others is shown in the final bequest of a major portion of his estate to his boyhood home, the city of Tomah, for the erection of a public library or for the purchase of a public playground or park.

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MEMOIR OF THOMAS M. JACKSON

BY I. C. WHITE

Presented extemporaneously, and will be printed in full when complete data are obtained by Doctor White.

The President then called for reports of committees. These were submitted as follows:

REPORT OF THE COMMITTEE ON PHOTOGRAPHS

The collection of photographs belonging to the Society has not received any additions for several years, and there has been no change in its condition in 1912. It contains a large number of fine pictures of geologic and physiographic features which are occasionally utilized by geologists for illustrating text-books or for lantern slides. A catalogue of the collection was published in volume 13 of the Bulletin of the Society. Ordinarily the collection is kept in my office in the Bureau of Mines in Washington, convenient for reference when I am in the city. During the past autumn it was loaned to Prof. W. M. Davis for use on the excursion given to the foreign geographers by the American Geographical Society, but it did not accompany the party. The collection is now being exhibited in the halls of the Geographical Society in New York, where it will be viewed by many teachers and others interested in geography and geology.

N. H. Darton,
Committee.

The report was accepted and the committee was continued.

REPORT OF THE COMMITTEE ON GEOLOGICAL NOMENCLATURE

No requests for information or for decisions on geologic nomenclature have come direct to the Secretary of the Committee on Geologic Nomenclature during the past year. No business has been transacted by the committee, therefore, in accordance with its original decision to take up no questions unless action on them was requested by members of the Society.

ARTHUR KEITH,
Secretary.

The report was accepted and the committee was continued.

RESOLUTION CONCERNING REPRINTING OF U. S. GEOLOGICAL SURVEY BULLETIN ON NAMES OF GEOLOGIC FORMATIONS

On motion, the Council was requested to communicate to the Director of the United States Geological Survey the feeling of the Society that a new edition of the Survey Bulletin on the names of geologic formations was greatly desired by teachers and other workers in geology.

COMMITTEE ON NOMENCLATURE OF FAULTS

The Secretary of the Society stated that the preliminary report of the committee had been distributed in May, 1912, to the fellowship and some other interested geologists, and that Chairman Reid would be present in the general session to offer the final report.

The Society then proceeded, at 11 o'clock, to the consideration of scientific papers.

TITLES OF PAPERS PRESENTED IN GENERAL SESSION AND NAMES OF DISPUTANTS

EXPERIMENTAL GEOLOGY, ONE OF THE LARGE SUBDIVISIONS OF GEOLOGY

BY FREDERICK EUGENE WRIGHT

Read in abstract from manuscript. Discussed by A. W. Grabau, A. L. Day, and J. E. Wolff.

REPORT OF COMMITTEE ON THE NOMENCLATURE OF FAULTS

BY HARRY FIELDING REID, CHAIRMAN

Presented in abstract from notes. Discussed by A. W. Grabau, W. M. Davis, A. H. Purdue, J. D. Irving, and L. V. Pirsson, with reply by H. F. Reid. On motion, the report was accepted for publication in the Bulletin, together with the discussion thereon.

The Society adjourned about 12.30 o'clock, and reconvened in three sections at 2.30 o'clock.

TITLES OF PAPERS PRESENTED BEFORE THE FIRST SECTION AND NAMES OF DISPUTANTS

The first section met, with President H. L. Fairchild as presiding officer and E. O. Hovey as Secretary, and took up the papers entered in the printed program under group A: Dynamic, Structural, Glacial, Physiographic.

NOTES ON THE STRUCTURAL GEOLOGY OF THE HANOVER DISTRICT, NEW HAMPSHIRE

BY JOHN W. MERRITT[1]

Read by title. Illustrative maps, photographs, specimens, and micro-sections were displayed in a special room provided for exhibition of material.

ON THE EFFECT OF HIGH PRESSURE ON THE PHYSICAL AND CHEMICAL BEHAVIOR OF SOLID SUBSTANCES

BY JOHN JOHNSTON AND L. H. ADAMS[2]

Presented in abstract extemporaneously by A. L. Day. Discussed by H. F. Reid and A. P. Coleman, with reply by A. L. Day.

STRUCTURAL FEATURES OF A PORTION OF SOUTHEASTERN IDAHO

BY R. W. RICHARDS AND G. R. MANSFIELD

Presented by title. Illustrative maps, diagrams, etcetera, were displayed in the exhibition room.

BANNOCK THRUST, A MAJOR FAULT IN SOUTHEASTERN IDAHO

BY R. W. RICHARDS AND G. R. MANSFIELD

Presented in abstract without notes by the junior author. Illustrated with lantern slides. Discussed by A. P. Coleman, E. Blackwelder, and H. F. Reid, with reply by Mr. Mansfield.

ANGULAR UNCONFORMITY AT CATSKILL

BY GEORGE H. CHADWICK

Presented by title. Illustrative maps and other material displayed in the exhibition room.

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[1] Introduced by J. W. Goldthwait.

[2] Introduced by A. L. Day.

DISPLACEMENTS OF TRIANGULATION STATIONS IN SUMATRA DUE TO AN EARTHQUAKE IN 1892

BY HARRY FIELDING REID

Presented in full without notes. Illustrated with lantern slides.

SOME STRUCTURAL FEATURES IN THE NORTHERN ANTHRACITE COAL FIELD

BY NELSON HORATIO DARTON

Presented in full without notes. Illustrated with lantern slides. Discussed by Wang and R. R. Hice.

GEOTHERMAL DATA OF THE UNITED STATES

BY NELSON HORATIO DARTON

Presented by title.

GLACIAL CIRQUES NEAR MOUNT WASHINGTON

BY JAMES WALTER GOLDTHWAIT

Presented in full without notes. Illustrated with lantern slides. Discussed by F. Leverett, H. F. Reid, J. B. Woodworth, G. H. Chadwick, and H. L. Fairchild, with reply by the author.

Adjournment of the section was taken about 5.15 o'clock p. m.

TITLES OF PAPERS PRESENTED BEFORE THE SECOND SECTION AND NAMES OF DISPUTANTS

The second section met at 2.35 o'clock p. m., under the chairmanship of Vice-President David White, and listened to the papers scheduled under Group B: Stratigraphic, Paleontologic,[1] Areal, and Cartographic. E. R. Cumings served as Secretary of the section.

NEW DATA ON THE RELATIONS OF THE OZARKIAN AND CANADIAN SYSTEMS

BY E. O. ULRICH

Read in abstract from manuscript. Discussed by C. Schuchert, with reply by the author.

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[1] Purely paleontological papers were referred to the Paleontological Society for reading.

CORRELATION PROBLEMS SUGGESTED BY STUDY OF THE FAUNAS OF THE EASTPORT QUADRANGLE, MAINE

BY H. S. WILLIAMS

Read in full from manuscript. Discussed by E. O. Ulrich, David White, and A. W. Grabau, with reply by the author.

STRATIGRAPHIC SUCCESSION OF THE CAMBRIAN FAUNAS IN THE ROCKY MOUNTAINS OF BRITISH COLUMBIA

BY C. D. WALCOTT

Presented by title in the absence of the author.

LOWER ORDOVICIAN AT GLENOGLE, BRITISH COLUMBIA

BY L. D. BURLING

Presented by title in the absence of the author.

GEOLOGICAL SECTION ALONG THE YUKON-ALASKA BOUNDARY BETWEEN YUKON AND PORCUPINE RIVERS

BY D. D. CAIRNES

Presented in abstract without notes. Illustrated with lantern slides.

RED BEDS BETWEEN WICHITA FALLS, TEXAS, AND LAS VEGAS, NEW MEXICO, IN RELATION TO THEIR VERTEBRATE FAUNA

BY E. C. CASE

Presented in abstract without notes. Illustrated with lantern slides. Discussed by David White, F. H. Knowlton, and E. C. Jeffrey, with reply by the author.

SHINARUMP CONGLOMERATE

BY HERBERT E. GREGORY

Read in full from manuscript. Illustrated with lantern slides. Discussed by A. W. Grabau, N. H. Darton, C. Schuchert, F. H. Knowlton, E. C. Jeffrey, and David White, with reply by the author.

PRELIMINARY DISCUSSION OF THE STRATIGRAPHY AND AGE OF THE PYROTHERIUM BEDS OF PATAGONIA

BY FREDERICK B. LOOMIS

Presented by title in the absence of the author.

FURTHER DISCOVERIES IN THE TACONIC MOUNTAINS

BY ARTHUR KEITH

Presented by title in the absence of the author.

PRELIMINARY GEOLOGICAL MAP OF THE NAVAJO-MOKI RESERVATION

BY HERBERT E. GREGORY

Presented in abstract without notes.

The section adjourned.

TITLES OF PAPERS PRESENTED BEFORE THE THIRD SECTION AND NAMES OF DISPUTANTS

The third section of the Society convened at 2.35 o'clock, with Vice-President I. C. White as Chairman and H. B. Patton serving as Secretary. The section took up the reading of the papers in Group C, as follows: Petrologic, Mineralogic, and Economic:

THE VARIOUS FORMS OF SILICA AND THEIR MUTUAL RELATIONS

BY CLARENCE N. FENNER

Read in full from manuscript. Discussed by F. E. Wright.

THE INDEX-ELLIPSOID IN PETROGRAPHIC-MICROSCOPIC WORK

BY FRED E. WRIGHT

Read in full from manuscript. Discussed by J. E. Wolff and E. B. Mathews.

IGNEOUS COMPLEX OF HIGH TITANIUM, PHOSPHOROUS-BEARING ROCKS OF AMHERST-NELSON COUNTIES, VIRGINIA

BY THOMAS L. WATSON AND STEPHEN TABOR

Read by title in the absence of the authors.

PETROLOGY OF A SERIES OF NEPHELINE SYENITE, CAMPTONITE, MONCHIQUITE, AND DIABASE DIKES IN MIDDLE SHENANDOAH VALLEY, VIRGINIA

BY THOMAS L. WATSON AND JUSTUS H. CLINE

Read by title in the absence of the authors.

THE NORTHUMBERLAND (NEW YORK) VOLCANIC PLUG

BY H. P. CUSHING

Read in full from manuscript. Illustrated with lantern slides. Discussed by L. V. Pirsson, J. V. Lewis, J. E. Wolff, and I. C. White.

LAVAS OF HAWAII AND THEIR RELATIONS

BY WHITMAN CROSS

Presented in abstract from notes. Discussed by R. A. Daly.

PRODUCTION OF APPARENT DIORITE BY METAMORPHISM

BY ARTHUR KEITH

Presented by title in the absence of the author.

MEDIA OF HIGH REFRACTION AND SOME STANDARD MEDIA OF LOWER REFRACTION FOR THE DETERMINATION OF REFRACTIVE INDICES WITH THE MICROSCOPE

BY H. E. MERWIN

Presented by title in the absence of the author.

CERTAIN SO-CALLED METEORIC IRONS OF CANYON DIABLO

BY CHARLES R. KEYES

Presented by title in the absence of the author.

NEW OCCURRENCE OF MONAZITE IN NORTH CAROLINA

BY JOSEPH HYDE PRATT

Presented in full without notes.

A NEW OCCURRENCE OF PISANITE, AND SOME LARGE STAUROLITES FROM DUCKTOWN, TENNESSEE

BY FRANK R. VAN HORN

Presented in abstract without notes.

The section adjourned.

PRESIDENTIAL ADDRESS

At 8 o'clock p. m., in Byers Hall of the University, H. L. Fairchild delivered his address as retiring President, his topic being

THE PLEISTOCENE FORMATIONS OF NEW YORK STATE

The address was followed by the complimentary smoker given in honor of the Geological Society of America, the Paleontological Society, and the Association of American Geographers by the local members of the three organizations.

SESSION OF SUNDAY, DECEMBER 29

In the afternoon the University Museum, containing celebrated collections in geology, mineralogy, and paleontology, and the University Art Museum were open to visitors. In the University Library there was displayed, in commemoration of the centenary of the birth of James D. Dana, a great series of the manuscripts and books written by the celebrated scientist and the medals, diplomas, and decorations that he received during his long career.

At 8 o'clock p. m. there was held in Lampson Hall a largely attended meeting in honor of the one hundredth anniversary of the birth of James D. Dana, arranged by Yale University in cooperation with the Geological Society of America. The meeting was presided over by Arthur T. Hadley, president of Yale University, who spoke as follows:

JAMES DWIGHT DANA CENTENARY

INTRODUCTORY REMARKS

BY ARTHUR T. HADLEY

In the latter part of the eighteenth century the stream of emigration from northern New England flowed westward up the Mohawk Valley, carrying with it the outposts not only of civilization, but of scholarship and of science. The academies of New York State a hundred years ago were schools of the first rank, out of which came many men of eminence in science and letters. It was from such stock and such surroundings that Dana came. He was by right of birth a pioneer.

Speaking to an audience that knows the pioneers of fact as distinct from those of fiction, I can describe Dana well by saying that he had the characteristics that belong to the type. There was the same determined readiness to submit to hardship and work under adverse conditions, and the same touch of poetry which enabled him to see through those hardships and adverse conditions to a goal beyond. His early professional experiences were pioneer experiences. He taught midshipmen in the United States Navy. The walls of his school-house were the rocks of Port Mahon; its playground was the slope of Vesuvius. A little later he served on the *Challenger* expedition—an expedition not unlike that of Darwin in the *Beagle*, but infinitely more perilous and ultimately involving actual shipwreck. He carried the spirit of the pioneer into his scientific work. All through his books we feel something of the inspiration of the poet, something of the joy of new discovery at every step. His first work, undertaken immediately after he left college, was in mineralogy. He found geology in large measure occupied in determining the order of deposits. He set himself to the task of finding out the physical processes by which those deposits were produced. In the great changes in the middle of the last century, by which science ceased to be a mere classification of phenomena and became in a truer and profounder sense an explanation, Dana was a leader. I shall not try to decide how much was due to him and how much was due to others. Any attempt at appropriation of credit was foreign to his nature. He was one of the group of men who found geology a chronicle and left it a history.

Hardly second to the joy of discovery in Dana's mind was the joy of imparting discovery to others as writer, as editor, and as teacher. In the days of the old curriculum, where a text-book course was given in each of several sciences, the question whether the students gained anything of its underlying spirit depended almost wholly on the teacher's personality. Every man who studied geology under Dana got below the letter and felt something of the spirit that gave life. He was, I think, at his best in the excursions which he took with his classes to points in the neighborhood of New Haven, where he would discourse with equal enthusiasm on the gorgeous minerals in the barytes mine of Cheshire or the cavities in the Shore Line Railroad cut that ought to have topaz but did not. If there was one thing that he seemed to love particularly it was glacier scratches, and it is needless to add that he was a connoisseur as well as an enthusiast. Well do I remember the time when the wag of the class surreptitiously made some glacier scratches of his own and called Professor Dana's attention to them in the presence of the class. He had taken much pains to have the direction right and the execution as lifelike as possible, and he thought the scratches would pass muster; but all the comment that he obtained was, "They look like the work of an Irishman."

The burden of ill health was one from which during the latter part of his long life Mr. Dana was never wholly free. But he carried it with indomitable fortitude, and in spite of his illness did work which would have seemed beyond the powers of a well man. He was fortunate in his love for the things he did, fortunate in the affection and admiration of a group of associates on the Yale faculty, most fortunate of all in his home and family life. A group of visible and tangible memorials of his work have been collected in the University library for this occasion. A more enduring monument, of a kind which would have appealed to him more strongly, is furnished by the research fellowship at Yale which bears his name and will enable others to carry on his work of discovery. But the greatest memorial of all is the affectionate remembrance of the man and of his work which lives in the hearts of us who come after him.

The following four addresses were then delivered:

DANA, THE MAN

BY WILLIAM NORTH RICE

James Dwight Dana was born February 12, 1813, and died April 14, 1895. His career of scientific work was exceptionally long and fruitful. His first scientific paper was published in 1835; his last in 1895—sixty years later.

The parents of Professor Dana were people of intelligence and high character, and the general influences of the home were altogether wholesome. There seems to have been, however, nothing in the environment of his childhood especially helpful toward a scientific career. In Utica Academy he received an impulse toward science from his teacher, Fay Edgerton, a man who was far in advance of his time in his methods of scientific instruction. Dana entered the sophomore class of Yale College in 1830, and was duly graduated in 1833. The strongest influence in his college life toward the shaping of his future career was that of the elder Benjamin Silliman, whose pioneer work in chemistry and geology was giving renown to Yale College. The year following his graduation he served as instructor in mathematics in the School for Midshipmen on the United States ship *Delaware* in a cruise in the Mediterranean. A letter to Professor Silliman, describing Vesuvius as he saw it at this time, was the first of his long series of papers published in the American Journal of Science. In 1836 he was appointed assistant to Professor Silliman. At that time he was devoting his attention chiefly to mineralogy, and his first important scientific work, the "System of Mineralogy," was published in 1837. It is remarkable that a book representing so large an amount of research should have been produced by a man only twenty-four years old and only four years out of college.

The four years, from 1838 to 1842, stand sharply in contrast with the simple and uneventful course of the remainder of his life. In those years he was one of the naturalists attached to the United States exploring expedition under the command of Lieutenant, afterwards Admiral, Wilkes. In the voyages of those years he crossed the Atlantic, Pacific, and Indian oceans, doubled the two great capes, traversed numerous coral archipelagoes in the Pacific, had two narrow escapes from shipwreck—one of them on a reef among the cannibal islands of the Kingsmill group—and actually suffered shipwreck on the bar at the mouth of the Columbia River. Dana did not participate in the cruise along the shore of the Antarctic continent, which was, in a purely geographical point of view, the most memorable achievement of the expedition. While some of the ships of the expedition were engaged in that Antarctic cruise, the naturalists were left behind for work in Australia and New Zealand. In the official distribution of the scientific work of the expedition, Dana was responsible for the geology and part of the zoology. The results of his work were embodied in three great reports, dealing respectively with zoophytes, crustacea, and geology, and published between 1846 and 1854. These years of world-wide travel vastly enlarged the sphere of Dana's geological observation and furnished much material for the thinking of later years. In the study of the coral archipelagoes of the Pacific he accumulated a vast amount of observation, which made him in after years the chief expounder and defender of the theory of subsidence, first offered by Darwin in explanation of barrier reefs and atolls.

In 1846 Dana became one of the editors of the American Journal of Science, with which he was associated for the remainder of his life. In 1850 he was elected professor of natural history in Yale, and in 1864 professor of geology and mineralogy. He did not, however, enter upon the work of teaching until 1855, the years preceding that date being devoted to the preparation and publication of the reports of the exploring expedition. He was engaged in the work of teaching, except for short times when he was disabled by illness, until 1890. In 1894 he became professor emeritus. His service as a teacher in Yale University was not only of great value to the institution and to the large number of students who came under his instruction, but was undoubtedly a benefit to him as an investigator. The work of exposition is an aid to clear thinking. If a scientific man is not required to teach so much as to exhaust his time and strength, his teaching fits him for better work as an investigator. It was the good fortune of Professor Dana to have enough of teaching and not too much. His most fruitful work was done during the period of his professorship in Yale. His greatest and most influential book, the "Manual of Geology," was published in 1862, and the fourth edition, the last important work of his life, was published in 1895.

The career of Professor Dana reminds us in various ways of that of Darwin. The two men were alike in the great duration of productive activity; in the number and variety of the subjects which engaged their attention; in the adventurous, world-wide exploration at the beginning of the career of each, and in the half-century of peaceful home life that followed. They were alike also in the experience of impaired health, and of a pathetic struggle to husband a scanty capital of physical vigor and endurance and make it yield the largest possible income of intellectual achievement.

I have elsewhere put on record[1] my own estimate of the work of Dana in the three sciences to which different periods of his life were chiefly devoted—mineralogy, zoology, geology. Today the discussion of his scientific work has been assigned to others most fit to appraise it at its true value. My duty is to speak of the general characteristics of the man.

The characteristic that most impressed all who really knew him was his profound sense of the sacredness of truth. With absolute sincerity he sought to know the truth and to tell the truth to others. No pride in what is wrongly called consistency made him unwilling to change his opinions. He seemed to take pleasure in confessing ignorance or error. In the third edition of his "System of Mineralogy," when he cast aside the classification and the Latin binomial nomenclature of the former editions, he wrote in the preface: "To change is always seeming fickleness. But not to change with the advance of science is worse; it is persistence in error." He said to me, in speaking of the changes introduced in the third edition of the "Manual of Geology": "When a man is too old to learn he is ready to die, or at least he is not fit to live." The frankness with which he changed his opinions and his teachings on the subject of evolution when more than threescore years of age is a striking illustration of his loyalty to truth. It was in 1874, in the second edition of the "Text-book of Geology," that he first avowed himself, though in somewhat qualified fashion, a believer in the doctrine which he had so earnestly antagonized. His conversion would probably have come somewhat earlier but for the fact that, on account of his impaired health at the time, he did not read the "Origin of Species" until several years after its publication. The same delicate sense of truth which made him so ready to change opinions made it possible for him to hold opinion in abeyance. He knew that he did not know some things and he would not assert plausible conjectures as truths. Professor Farrington has preserved[2] some of the aphorisms which he uttered from time to time, which might well be adopted as maxims by all students of science. "I think it better to doubt until you know. Too many people assert and then let others doubt." "I have found it best to be always afloat in regard to opinions on geology."

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[1] Jordan: Leading American men of science. New York, 1810, pp. 233-268.

[2] Journal of Geology, vol. 3, p. 335.

His liberality in the treatment of difference of opinion was another phase of his devotion to truth. The pages of the Journal of Science were always freely open for the presentation of views most widely divergent from his own. “More,” he said, “could be learned by studying unconformities than conformities.”

His loyalty to truth was in part an intellectual and in part a moral trait. Intellectually it was related to the clearness of his conception. It is the man who never knows exactly what he thinks that falls most easily into the vice of saying something different from what he thinks. But Dana's character was intensely ethical, and with him ethics was always sanctified and glorified by religious faith. In his view disloyalty to truth was infidelity to God. The influences of his childhood home were strongly religious, and in his early manhood he made public profession of Christian faith, uniting with the First Congregational Church in New Haven. His letters, written amid perils of shipwreck and cannibals in the exploring expedition, reveal the strength of his faith in the providential care of a Heavenly Father. His patience under the restraints imposed upon him by the impairment of his health and the serene light which brightened the long evening of his life were doubtless in part due to a naturally cheerful spirit, but surely in large part due to his religious faith. A few months before his death he wrote to Prof. J. P. Lesley: “I used to have a spring in my walk and get delight out of it. But for a little over a month my heart has compelled me to take what I should before have called a creeping gait. Such encroachments are reminders that the end is coming. But it will be peace, rest, and, I believe, joy unending. Life were worth living if it were only for the end.”

One is reminded of Browning's noble lines:

> “Grow old along with me!
> The best is yet to be,
> The last of life, for which the first was made.”

As a thinker Dana was eminently characterized by breadth of view. Though facts might be, as Agassiz so nobly said, “the words of God,” they were meaningless unless they could be arranged in sentences. Dana was eminently a generalizer and a systematizer. The “Manual of Geology” is indispensable to every American geologist for its encyclopedic array of facts; but the general conception of the meaning of geological fact with which the whole book is luminous is the greater glory. If Dana sometimes mistook analogy for identity, and sometimes grouped facts in a pseudo-system, he only showed “the defects of his qualities.” The only man who has made no unsound generalizations is the man who has never generalized at all.

There is a certain intellectual kinship between the philosopher and the poet. The loftiest generalizations of science involve a flight of imagination approaching the poetic. The minds most gifted with the power to see the scientific meaning of natural phenomena are often most keenly sensitive to the inspira- Coral Islands” and gemlike sentences which flash here and there from the pages of the “Manual of Geology” show a poet's sense of nature's manifold and resistless charm.

Dana's personal appearance was at once attractive and impressive. The flash of his eyes and the exquisite sweetness of his smile will ever haunt the memory of all who knew him. His latest portrait is the most impressive one. The thin, eager, vivacious, kindly face, with its halo of silver hair, was inspiring in its dignity and sweetness. For him the hoary head was a crown of glory.

The quickness of all his movements was remarkable. Even in old age he walked uphill and down at a pace which students found it easier to admire than to imitate. The quickness of his physical movements was an expression of the sensitiveness of nervous organization which gave such intense vivacity to his mental work.

The restraints imposed by the condition of his health isolated him from society in general. Yet he was delightfully companionable to those who had the privilege of entering the precincts of his quiet and secluded life. His conversation was enlivened with a delicate humor, and in controversy he could be sarcastic. His courtesy was the expression of real kindness of heart. His helpful interest in the work of younger scientific men has left rich store of grateful memories. As son, brother, husband, father, friend, his life in all the relations of most intimate affection was pure and gentle.

His was a genius to be admired, a character to be reverenced, a personality to be loved.

DANA, THE TEACHER

BY EDMUND OTIS HOVEY

Geology at Yale, though it covers the history of the science in this country, is but little more than a century old, the first lectures in what was then considered a dangerous and revolutionary subject having been given by Prof. Benjamin Silliman, the elder, in 1806. Just fifty years later, February 18, 1856, Prof. James Dwight Dana began his active class-room work as the Silliman professor of natural history, the chair having been established a few years previously by Prof. Edward E. Salisbury for the purpose of keeping at Yale the rising naturalist, whose fame was already more than national. Professor Dana, therefore, was no longer strictly a young man when he began his work in the class-room. Forty-three years had passed over his head, but more than thirty of them had been years of wonderful preparation. A collector of natural history specimens as a mere child, his bent had been fostered in the, for those days, unusually ambitious science department of the Bartlett Academy, at Utica, N. Y.

Daniel C. Gilman, Dana's biographer, quotes a letter from Dr. M. M. Bagg, of Utica, descriptive of this school, and Fay Edgerton, its science master, who was a pupil of Amos Eaton, one of America's pioneers in geology, who in turn had been a student under Silliman. Edgerton was by nature a teacher, and he took his pupils on long walks into the neighboring country, "showing them (according to Doctor Bagg) where to go in pursuit of whatever was instructive or curious, assisting them in the naming and care of their specimens and inspiring them with (his own) zeal for natural science. During the long summer vacations he (Edgerton) made lengthy excursions with half a dozen or more of his class to distant parts of the State or neighboring ones, visiting localities that abounded in particular rocks or minerals, and bringing home stores for their own or the school collection. These excursions were made almost wholly on foot, a single horse and wagon accompanying the party to carry their scanty wardrobe and relieve the oft-burdened mineral satchel borne by each of them, until such time as they reached a suitable place for shipment."

I have quoted thus at length from Doctor Bagg's letter, because Professor Dana used often in conversation to refer to those early days at Utica and the advantage that a country boy had over a city boy in the study of nature, ascribing to Mr. Edgerton the crystallizing into permanency his own inclination toward nature study. I do not recall his ever mentioning Asa Gray as being one of his teachers, though the great botanist succeeded Edgerton at Bartlett Academy before Dana left home for New Haven, and Dana and Gray were lifelong and fast friends.

Dana, as he himself said in his inaugural address as professor, was attracted to Yale in 1830 by the elder Silliman, another marvelous teacher, then in the zenith of his fame. Thus we can trace the influence of one great teacher on another—Silliman on Eaton, Eaton on Edgerton, Edgerton and Silliman on Dana, Dana on many of the geologists of the present day.

In 1833 and 1834 Dana spent sixteen months on a United States naval vessel, cruising to the Mediterranean as a teacher of mathematics to midshipmen. Then came a period of three years without a position, except temporarily as assistant to Silliman, fruitful in producing the first edition of his "System of Mineralogy," a remarkable book for a young man of 24 to prepare. After this period came the United States exploring expedition under Captain Wilkes, 1838-1842, giving Dana an unequaled opportunity for accumulating data and experience, and this was followed by fourteen years devoted to getting out his truly monumental reports on the zoophytes, the geology and the crustacea of the trip, and to the preparation and publishing of the second edition of his "System of Mineralogy," his "Manual of Mineralogy," the third edition of the System, coral reefs, and islands, and the fourth edition of the System, besides many long and short articles that appeared in the American Journal of Science and elsewhere—about 7,000 pages of printed text, besides hundreds of plates and figures, coming from his pen in these years.

These thirty years, as we may say, of preparation brought him to his professorship with a fund of knowledge and experience possessed by none of his colleagues in geology. Except for periods of enforced rest, when the frail body was allowed an opportunity to recuperate from the strain put on it by the intensely active brain, Professor Dana was on the active teaching force of Yale College for about thirty-five years, or until the fall of 1890, when persistent ill health forced him to give up class-room work. In 1892 he formally relinquished his professorship and two years later was made professor emeritus.

At first he had classes in mineralogy as well as geology, but as he grew away from the narrower science he retained those in geology alone, an elementary required course for the college seniors in the fall term, followed by an advanced elective course in the spring, with occasional graduate students, constituting the program of directly instructional work that fell to his lot, at least during the latter part of his career.

It is quite the custom in many quarters to inveigh against the usage that prevails in most American universities and colleges of requiring full professors to give elementary instruction in the class-room. There is this to be said in its favor, however, that it widens the influence of the master mind, arouses more thought in the average undergraduate than can be engendered by an in-experienced or mediocre man, and makes the great men of science, letters, and art something more than mere names to hundreds and even thousands of influential men all over the country. One of my own classmates, who has never pretended to any special knowledge of geology, was so impressed with the exposition in the required course of the Darwin-Dana theory of the formation of coral islands that he offered to fit out an expedition to enable Professor Dana to accomplish his favorite scheme of sinking one or more deep borings in some atoll of the South Pacific to test it. The naturalist, however, was already 71, and he reluctantly decided that he was too old to undertake the work. Professor Dana's lectures, nevertheless, were an important factor in influencing this young man to foster science with a portion of his wealth during the succeeding years.

My own experience under Professor Dana began in the fall of 1883, in the required geology course, and well do I recall the courtly gentleman in the class-room and on the field excursion. Peabody Museum was then a new building and he was very proud of it, for he had had much to do with the plans for its internal arrangement. The geology lectures were given in the large hall, on the ground floor, that still serves the same purpose, and its original conveniences were devised by Professor Dana. Promptly on the hour, the modest and unassuming but still impressive man would appear from his office and begin lecture or recitation with a nervous energy that bespoke the industry and concentration which enabled him to accomplish the great amount of work that stands to his credit. Lectures were crowded with fact and condensed in delivery; a student could not afford to miss a word. Recitations went forward with no waste of time. I recall no obvious effort at discipline in the classroom, the personality of the instructor seeming to eliminate all thought of disorder from the mind of even the most irresponsible student.

In recitation hearing Dana was confined to the text-book before him, evidently thinking it a waste of energy to commit to memory himself the exact limits of the knowledge that could fairly be expected from the class; but his remarks on the subject of the day were drawn from his own wide fund of personal experience, which was always presented in the most impersonal way, supplemented by up-to-date reading. He had wonderful facility in assimilating and presenting the facts and worthy ideas brought out by others, but at the same time he had the rarer faculty of remembering the sources of such facts and ideas and the candor to give credit where credit was due. Professor Dana was, however, no mere recitation hearer. Class-room work was onerous to him, I think, though he was faithful to it through the honesty of his nature, which did not permit him to slight any duty or shirk any task. The boys who worked and who manifested a real interest in the earth sciences received full measure of his time and his talents; but those who tried to "bluff" their way through his classes encountered serious obstacles in the keen wit of the kindly old gentleman.

The excursions of senior year took us to West, Pine, Mill, and East Rocks, forming the familiar rampart of diabase sills and dikes bounding New Haven on the north; to the Woodbridge Hills and Judges Cave, to see a train of huge glacial boulders; to the kettle holes of Beaver Pond meadows and cross-sections of the New Haven sand plain; to Red Rock and the faultscarps of Triassic sandstone in Fair Haven and East Haven. One exceptional trip was that made by some of the elective class to the Tilly Foster iron mines at Brewsters, New York. Those were old-style excursions, full of didactic conversation without much inductive work; but "induction" was not the fad then. The crowds of students, nevertheless, derived a world of benefit from their intercourse with their famous teacher, whose encyclopedic fund of knowledge was given as freely as air to the honest inquirer after truth, while his keen questions were provocative of thought and instructive discussion.

Professor Dana had no use for the trifler. We were examining the strongly marked contact phenomena in the Triassic arkose of Mill Rock beside the trap dike in the road at the foot of Lake Whitney, when one of my classmates submitted a piece of hard-burned brick with the question, "What do you think that is?" Quick as a flash came the retort, "A foolish question by an impertinent student."

Judging from my own experience of three years, 1886-1889, Professor Dana was extremely painstaking with his graduate students, particularly in book work. He left us a good deal to our own devices in field work, not supervising us as closely or pushing us as hard then as he would doubtless have done had he been younger and stronger and less absorbed in his own studies and writing. Still, college geological departments thirty years ago were only just beginning to develop the efficiency in field instruction that they have since attained, and the class-room method was carried too much into the seminar.

In the intimate acquaintance with Professor Dana to which the graduate student attained, the observations on men and methods let fall by the teacher were invaluable in their effect on the student. Respecting the father of one of the present geological faculty at Yale, Professor Dana remarked, when he heard of his untimely death, "His death causes a distinct loss to geological science. He was a keen observer, a painstaking collector of facts, a careful man in statement, conservative in deductions, open-minded as to opposing theories. He was trustworthy." Professor Dana could not tolerate another geologist of wide fame whose conclusions, though brilliant, were based on hasty and insufficient field study. "No man," said Dana, "can grasp the facts of the metamorphic rocks and their theoretical bearing by looking at the country as he drives along in a buggy."

He was always opposed to dogmatism either in matter or manner. His mind was ever open to the reception of new facts and new explanations of long known facts. The mere circumstance that *he* had published a statement of fact or theory did not lead him to cling to it against evidence. In the preface to the third edition of the "System of Mineralogy" (1850), which was the one in which he abandoned the dual nomenclature for minerals which he had elaborately worked out, he said: ". . . To change is always seeming fickleness. But not to change with the advance of science is worse; it is persistence in error. . . ." Throughout his long life this was his constant attitude of mind and it was, naturally, reflected in his class-room work. This is perhaps shown most strikingly in his teachings regarding evolution, from the early days (Crustacea, 1854), when he advocated the doctrine of the special creation of species, to the later period of his life, when he favored the view of *evolution through variation* ("Manual of Geology," fourth edition, 1895). The same characteristic was shown in his instructions to me as a graduate student, when I began work under him on the Triassic trap dikes and sheets east of

New Haven. He said, "I have always regarded the trap as intrusive after the tilting of the sandstone, but an entirely different theory is now being advocated for the northern part of the Connecticut Triassic. I want you to ascertain the facts for the New Haven region and determine the theory that applies to them, without reference to its authorship." And he accepted with equinimity the changes in theory that became necessary from the study.

He was much interested in the progress of this investigation, and once took Dr. George H. Cook, of New Jersey, out to see some newly found exposures. Doctor Cook was somewhat slow in getting out of the carriage, but Professor Dana was as spry as a cat. He apologized for helping Doctor Cook, on the ground that the latter was the elder. Comparison of ages showed to the surprise of both that the New Jersey man was younger by several years than his more agile colleague. As a matter of fact, Professor Dana was noted for the rapidity with which he got over the ground when leading a geological excursion. He seemed to begrudge the time that was consumed in passing from one point of geological interest to another.

He was an indefatigable and charming letter-writer, as his biography shows, and the kindness of his heart led him not to neglect his former pupils. Within a year of his death, while being allowed to work only three hours a day and while every moment was precious for the completion of the fourth edition of his "Manual of Geology," he devoted part of one at least of those valuable working periods to writing a long letter elucidating an intricate problem in geology for the benefit of one of his old students.

I can not close this all too brief tribute without referring to his work as an editor, and especially to part of his work as an author. For a half century he put the impress of his personality on the American Journal of Science, making it a training school for American scientists and a necessity for the college professor and the laboratory and field worker. As the author of the "System and the Manual of Mineralogy," the "Manual and the Text-book of Geology," and the "Geological Story Briefly Told," Professor Dana made his impression on every geological class-room in the country. The influence of a great teacher never dies, and James D. Dana was a great teacher.

DANA, THE GEOLOGIST

BY GEORGE P. MERRILL

In accepting the invitation to speak tonight on Dana as a geologist I confess to having been controlled in part by a desire to make known to you how Dana impressed one who had never fallen under his personal influence, for I knew him but slightly. My knowledge and my opinions are based largely on what I have gained through reading, though naturally molded to some extent by the opinions of friends. In short, it seemed that perhaps I might speak of his work from the cold-blooded standpoint of an historian, unbiased by personal contact, never having antagonized and never working with him except as both were laboring in a common cause.

Let us consider for a moment the essentials for good geologic work:

1st. One must be a good observer.

2d. He must be sufficiently grounded in certain basal sciences to enable him to draw legitimate conclusions from what he observes.

3d. He must know what other workers have done, and be able to utilize to advantage their work and conclusions.

4th. If he is a *great* geologist he must possess a creative imagination and be master of both inductive and deductive methods of reasoning.

5th. He must have staying power.

Now, I have found no man, in my readings on American geology, who possessed these qualities to the same degree as Dana. In turning through that masterly compendium which has come edition after edition from his hand one can but be impressed with the grasp he had on the literature in all its phases: how no writer, however humble or amateurish, was overlooked if his work was of value, and how, notwithstanding the mass of detail, often contradictory and inconclusive, the conclusions drawn were always clear and logical.

Dana, almost from the beginning of his career, showed a capacity for the larger problems, but by no means ignored the smaller ones. He was no mere closet geologist or describer of species; neither was he parasitic on the work of others. In no other branch of science than that of geology can it be said with a greater degree of truth that "a thought is his own who kindles new youth in it." Thus Dana made others' work his own, absorbing into his mind the results of all laborers in the field and putting into them new youth. "And we call a thing his in the long run who utters it clearest and best," wrote Lowell, and he could not have better expressed it had he known Dana and written it with him in mind.

If any who are present tonight will read the writings of Dana, and particularly those that appeared in the American Journal of Science and the two-volume report of the Wilkes Exploring Expedition, and note the careful, detailed manner in which his facts are presented, and the calmly judicial method of disposing of them, I can but feel that they will agree with me in considering him the master mind of his time. It needs but a glance at his bibliography to show us his mental breadth. I will quote a few titles, selected almost haphazard, by way of illustration:

> On the areas of subsidence in the Pacific, as indicated by the distribution of coral islands. 1843.
>
> On the analogies between the modern igneous rocks and the so-called primary formations, and the metamorphic changes produced by heat in the associated sedimentary strata. 1843.

He showed in this second paper (1) that the schistose structure of gneiss and mica slates is no satisfactory evidence of sedimentary origin; (2) that some granites having no schistose structure may have a sedimentary origin, and (3) that the heat-producing metamorphism was not applied from beneath, by conductivity from some internal source, but through the heated submarine volcanic waters of the ocean. In other words, the rocks were not hypogene, as explained by Lyell, but epigene. In favor of (1) he showed that many lavas had an original laminated structure; that when crystals of any mineral form simultaneously they tend to assume a parallel structure; faces of like cleavage lie in the same direction. The unequal rectangular planes of fracture in granitic rocks correspond, therefore, with the cleavages of the contained feldspar. Though written in 1843—more than sixty years ago—this paper may be read with profit by the student of petrology today.

On the origin of continents. 1846.

Geological results of the earth's contraction in consequence of cooling. 1847.

Origin of grand outline features of the earth. 1847.

In these three papers, it will be recalled, he announced it as his belief that what are now oceanic areas were at one time the more intensely heated portions of the earth's crust, and hence had on cooling undergone the greatest amount of contraction and consequent depression; also that, contrary to the views of the Rogers brothers, the Appalachian uplift could be accounted for by lateral thrust rather than through a force acting from beneath. Further, that the age of the mountains could not be determined by the direction of their trend. These papers I will refer to again.

On the plan of development in the geological history of North America. 1856.

In this paper he called attention to the now commonly recognized fact that, so far as the American continent is concerned, the greatest mountain chains border on the larger oceans, and that vulcanism is characteristic of these bordering chains and oceanic islands rather than continental interiors; and still again, that oceanic depression and continental uplift have both been in progress with mutual reaction from the beginning of the earth's refrigeration. The original V-shaped character of the North American continent was due to forces acting from the two oceans.

On some results of the earth's contraction from cooling, including the origin of mountains and the nature of the earth's interior. 1873.

In this we find Dana once more turning to the subject of his papers of 1847 and 1856, and here is well illustrated his capacity for utilizing the work of others. Not contenting himself with mere criticism, he pointed out limitations and errors, if such existed, at times actually strengthening a weak argument and incorporating the whole into his own, adding to it new material to still further bridge the existing chasms. Adopting in part the views of Le Conte, he here recognized the existence throughout a considerable portion of geological time of a thin stratum of liquid matter beneath the crust and a solid nucleus whereby oscillation would be rendered possible. He summed up his conclusions as follows:

"(1) In mountain-making on continental borders the oceanic crust through its lower portion exercises during the process of crystal contraction an upward thrust against the borders of the continent.

"(2) Among mountain elevations there are those which, like the Alleghanies, are the result of one process of making, or are *monogenetic*, and those that are a final result of two or more processes at different epochs, or are *polygenetic*."

On a case in which various massive crystalline rocks, including soda-granite, quartz diorite, norite, hornblendite, pyroxenite, and different chrysolitic rocks were made through metamorphic agencies in one metamorphic process. 1881.

On the decay of quartzite and the formation of sand, kaolin, and crystallized quartz. 1884.

On Taconic rocks and stratigraphy, with a geological map of the Taconic region. 1885 and 1887.

On the origin of the deep troughs of the oceanic depression. Are any of volcanic origin? 1889.

In this last paper he showed that these troughs could not be due to undermining by extraction of volcanic material nor to erosion by oceanic currents, nor, again, to the ordinary laws of isostacy as we now understand them. He felt that we must look to deeper lying causes for their solution. This paper well illustrates a characteristic voiced by the speaker who has preceded me: "I have found it best to be always afloat in regard to opinions in geology."

As editor of the American Journal of Science, a position which he occupied from 1846 until almost the day of his death, Dana naturally had occasion to review either himself or through assistants nearly every publication on geological matters which appeared in America, with incidental reference to much that was foreign, and the manner in which these papers were handled is a striking illustration of his mastery of detail and breadth of view. In his original papers—original as distinguished from reviews—he covered a range of subjects that would seem almost absurd in one of the present day, as I have already indicated—dynamic, structural, paleontologic, petrographic—papers dealing with the minutest structural details to those in which world history is involved. The only branch which he let alone, even ignoring it largely in reviews, was that relating to the origin of ore deposits, and this, I think, may be accepted as another illustration of the breadth and acumen of the man!

In reading his papers, however, one must bear in mind the condition of knowledge at the time they were written. Those on the geologic results of the earth's contraction and the grand outline features of the earth were dangerously theoretical and the subject one to delight the heart of the old-time cosmogonist. Yet though he wrote, as Huxley would say, "with one eye on fact and the other on Genesis," his vision never became confused nor his reason confounded. He saw processes and effects, conceived certain possibilities, and reasoned to conclusions. These conclusions, in the light of today, may not in all cases be correct, but in their time they appeared justifiable. Other men may have made more striking observations, perhaps more brilliant discoveries, but they had not his breadth and staying power.

Dana's early experience was undoubtedly of a kind best suited to bringing out the latent qualities of a broad mind. It will be remembered that in 1833, when little more than twenty years of age, he became an instructor in mathematics in the navy, and in this capacity visited the Mediterranean region and made the condition of Vesuvius the subject of his first geological paper. Again, from 1838 to 1842, he was geologist and mineralogist to the Wilkes Exploring Expedition, and as such made the long trip around Cape Horn to the islands of the South Pacific and back across the continent. That he utilized to advantage the opportunities thus afforded there can be no question.

Passing today the window of the room formerly occupied by him as a study, I looked up half expectant of seeing that thin, keen, intellectual face, surmounted by its halo of snow-white hair; but it is gone for all time. The memory of it shall remain so long as memory itself remains. The work he accomplished shall remain so long as a study of the fundamental problems of human existence is pursued in our universities and so long as a knowledge of human achievement remains an essential of human culture.

DANA, THE ZOOLOGIST

BY JOHN M. CLARKE

In nothing, I believe, does the genius of this extraordinary and many-faceted mind shine more brightly than in its achievements in zoology. Professor Dana accomplished results in this science in his actually brief contact with it that would have made a large harvest for the life work of any special student of it. His dealings with the science were in a sense so brief as to be quite incidental; and yet, brief and incidental though they may have been, they gave him very positive and authoritative standing among the zoologists of his day and of this day. Professor Dana was a mineralogist by inception, a geologist in fruition. Zoology, it may be fairly said, was thrust on him. It was again the Wilkes Expedition which forced the development of his interest into this science. He was detailed, on board the *Peacock*, as mineralogist of the expedition. There was no other man in the fleet that had a like function. Titian Peale was "naturalist" aboard the same ship; Pickering and Couthouy were "naturalists" aboard the *Vincennes;* Rich and Brackenridge were botanists. It would seem as though the work of the "naturalist" were well provided for, yet to the mineralogist fell the lot of making rather the most distinguished record of all these naturalists in their own field.

The situation and its conclusions are after all not difficult to understand. What was there for a mineralogist in the harbors of the southern continent or among the atolls and volcanic islands of the South Sea? What of geology was there for a mineralogist so situated in the 1830's? Were these places that could excite the ardor of a mineralogist? The mineralogist of the expedition indeed never made a report. There was a report of serious import on geology, which was concerned largely in the discussion of secular changes in level on continental coast and island outline. But all through his narratives, both on geology and zoology, we can see writ large the intense, almost boyish enthusiasm with which he cruised and waded among the coral reefs and atolls, sounding, dredging, gathering their brilliant and eternally variant life forms; and here, too, we may see clearly that the mineralogist was working with two sciences, each of which was collateral to the other, and it would be impossible to say whether his zoological studies then were not quite as essential to his geological conclusions as were his geological determinations to his zoology. At all events the older naturalists of this expedition, as well as the commander, realized that these studies had made Mr. Dana the man to undertake not only the report on the geology of the expedition, but the special reports on the zoophytes and the Crustacea. Ten years and more were given to the preparation of these great reports, and I wonder if the zoologists of today realize that Dana published, *inter alia*, in these sumptuous and rare volumes descriptions of over 200 species of Anthozoa and 680 species of Crustacea. In 1855, when the last of these reports had appeared—the Crustacea—Dana stood as the world's leading authority on these two divisions of the animal kingdom. As ever and in all things scientific, he had attained not merely excellence but supremacy.

Now I take it as an extraordinary fact that, these great undertakings being accomplished, only the echoes of them remained through his later career. Predestined as a geologist, it seems that all his various departures into other sciences were to harvest out their bearings on his interpretation of the earth. To the philosophical aspects of his zoology he did recur—to his conception of cephalization as a guiding factor in evolution—long before he accepted the prolegomena of natural selection, and also to his zoophytes as contributions to his views on coral-island growth. Let us look, for a sample year, to 1853, when his fascinating book on "Coral Reefs and Islands" came out, a book to appear in two subsequent editions, under the better known title of "Corals and Coral Islands," in which a picture has been painted of these islands that is equaled in sentiment only by Chamisso, and in science perhaps not at all. In this year Professor Dana published besides his Coral Islands papers on changes of level in the Pacific; the effect of temperature on the vertical distribution of marine species; mineralogical notices; the isomorphism of sphene and euclase; an isothermal oceanic chart; consolidation of coral formations; a supposed change in ocean temperature. Up to 1866 he published a little each year, chiefly on the philosophical lines of zoology; on classification, parthenogenesis, cephalization, homologies, and parallel development; on man's zoological place, and even on the origin of life; and then his versatile mind seems to have become so entirely impregnated with his life's chief purpose that he excluded organic problems, perhaps not from his thoughts, but at least from his special treatises, and never again for nearly thirty years, until 1894, the year before his death, did he recur to this subject, and the last of his long list of scientific papers was on the derivation and homologies of some articulates.

Another fact in this distinguished record, of singular and rather extraordinary meaning, is that, notwithstanding Professor Dana's intimate concern with both the living and the dead earth, he permitted this strong combination to lead him but a very short distance into the byways of paleontology. He did indeed describe some Paleozoic corals and some Australian Tertiary shells, but this quite impassively, and the dynamics of life seemed to concern him vastly more than its history. It would be historically interesting to know the reasons for this avoidance of what would seem the most natural path to take for a man armored as he was. I am not aware that the question has been answered or even asked. One might, however, guess that the invitation into the paleontological thoroughfare in this country during his creative years was not compelling to a man of his ideals. At all events and when all is said, it is entirely obvious that by Professor Dana his exceptional and philosophic acquaintance with zoology was held to be the handmaiden of his chosen science of geology.

SESSION OF MONDAY, DECEMBER 30

The Society convened at 9.45 o'clock a. m. in general session, President H. L. Fairchild in the chair. The following report was presented by the Auditing Committee:

REPORT OF AUDITING COMMITTEE

The Auditing Committee report that they have checked the receipts as shown by the Treasurer's printed report with the original item of entry, and found them correct. They have compared the vouchers of expenditure with the canceled checks and with the reported expenditures; also the balance on hand December 2, 1912, with the balanced bank book, and found the same correct. They have directed Whitman Cross, a member of the committee, to visit Baltimore, examine the securities in the hands of the Treasurer, and to report to the President and to the Secretary of the Society the result of said examination.

By vote this report was accepted and the Council report was taken from the table, accepted, and ordered printed in full in the Proceedings.

TITLES OF PAPERS PRESENTED IN GENERAL SESSION AND NAMES OF DISPUTANTS

The Society then proceeded to the consideration of the scientific papers in the general session.

SPECULATIVE NATURE OF GEOLOGY

BY W. M. DAVIS

Presented in full without notes. Discussed by A. W. Grabau and H. L. Fairchild, with reply by the author.

BEARING OF RECENT CLIMATIC INVESTIGATIONS ON GEOLOGICAL THEORIES

BY ELLSWORTH HUNTINGTON

Presented in full without notes. Illustrated with lantern slides. Discussed by A. C. Lane, W. Cross, and W. N. Rice, with reply by the author.

The following two papers were given together:

PIEDMONT TERRACES OF THE NORTHERN APPALACHIANS AND THEIR MODE OF ORIGIN

POST-JURASSIC HISTORY OF THE NORTHERN APPALACHIANS

BY JOSEPH BARRELL

Presented in abstract without notes. Illustrated with lantern slides. Discussed by Frank Leverett, D. W. Johnson, W. M. Davis, M. R. Campbell, and N. H. Darton, with reply by the author.

The general session adjourned at 12.30 o'clock p. m.

TITLES OF PAPERS PRESENTED BEFORE THE FIRST SECTION AND NAMES OF DISPUTANTS

The first section convened at 2.40 o'clock p. m., with President Fairchild in the chair and L. G. Westgate acting as section secretary. The following papers were offered:

RECENT CHANGES IN THE ASULKAN GLACIER

BY HEINRICH RIES

Presented in abstract without notes. Illustrated with lantern slides.

EVIDENCE OF VERY EARLY GLACIATION IN OHIO

BY GEO. D. HUBBARD[1]

Presented in abstract without notes.

THE BEGINNINGS OF LAKE AGASSIZ

BY FRANK LEVERETT

Presented in full without notes. Discussed by J. B. Woodworth, H. L. Fairchild, H. F. Reid, and A. P. Coleman; reply by the author.

REMARKABLE DEFORMATION OF THE ALGONQUIN BEACH

BY FRANK LEVERETT

Presented in full without notes. Discussed by H. L. Fairchild, A. P. Coleman, J. B. Woodworth, J. W. Spencer, and J. W. Goldthwait; reply by the author.

THE PLEISTOCENE SUCCESSION IN WISCONSIN

BY SAMUEL WEIDMAN

Presented in abstract by Frank Leverett, in the absence of the author, on account of its bearing on the following paper.

THE IOWAN DRIFT

BY FRANK LEVERETT

Presented in abstract without notes. Discussed by J. W. Woodworth and A. P. Coleman, with reply by the author.

PRE-WISCONSIN GLACIAL DRIFT IN THE REGION OF GLACIER PARK, MONTANA

BY WILLIAM C. ALDEN AND EUGENE STEBINGER

Presented by title in the absence of the authors.

CANYON AND DELTA OF THE COPPER RIVER IN ALASKA

BY LAWRENCE MARTIN

Presented by title in the absence of the author.

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[1] Introduced by G. F. Wright.

CONTRA-IMPOSED SHORELINES

BY CHARLES H. CLAPP[1]

Presented in abstract from notes. Illustrated with lantern slides. Discussed by D. W. Johnson.

SUBMARINE CHAMÆCYPARIS BOG AT WOODS HOLE, MASSACHUSETTS, AND ITS RELATION TO THE PROBLEM OF COASTAL SUBSIDENCE

BY DOUGLAS W. JOHNSON

Presented in full without notes. Discussed by J. W. Spencer.

PEAT DEPOSIT OF GEOLOGICAL INTEREST NEAR NEW HAVEN, CONNECTICUT

BY C. A. DAVIS

Presented by title in the absence of the author.

EARLY PALEOZOIC PHYSIOGRAPHY OF THE SOUTHERN ADIRONDACKS

BY WILLIAM J. MILLER

Read in abstract from manuscript.

LEVEL OF MAXIMUM PRECIPITATION AS A FACTOR IN THE GLACIATION OF MOUNT RANIER

BY F. E. MATTHES[2]

Presented by title in the absence of the author.

CHARACTERS OF THE OLDER SECTIONS OF THE NIAGARA GORGE AND THEIR CORRELATION WITH GREAT LAKES HISTORY

BY FRANK B. TAYLOR

Presented by title in the absence of the author.

The second section having finished on Saturday the papers on its program, merged on Monday with the meeting of the Paleontological Society.

TITLES OF PAPERS PRESENTED BEFORE THE THIRD SECTION AND NAMES OF DISPUTANTS

The third section met at 2.35 o'clock, with Vice-President I. C. White in the chair and E. O. Hovey serving as Secretary.

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[1] Introduced by D. W. Johnson.

[2] Introduced by M. R. Campbell.

MICROSTRUCTURE OF TITANIFEROUS MAGNETITES

BY JOSEPH T. SINGEWALD, JR.

Read in full from manuscript.

ORIGIN OF GRANITES AS WELL AS METACRYSTALS BY SELECTIVE SOLUTION—A RECANTATION

BY ALFRED C. LANE

Read in full from manuscript. Discussed by G. P. Merrill and E. S. Bastin.

NEW CLASSIFICATION OF NATURAL WATER

BY CHASE PALMER[1]

Read in full from manuscript. Discussed by A. C. Lane and W. H. Emmons.

PRE-CAMBRIAN STRUCTURE OF THE NORTHERN BLACK HILLS AS BEARING ON THE HOMESTAKE ORE BODY

BY SIDNEY PAIGE

Read in full from manuscript. Discussed by J. D. Irving.

H. B. Patton took the chair by invitation of Vice-President White, and

NOTE ON A VERY DEEP BORING FROM NEAR MC DONALD, PENNSYLVANIA

BY I. C. WHITE

was presented in full without notes. Discussion by J. F. Kemp, A. C. Lane, and F. R. Van Horn, with reply by the author.

GULF COAST PETROLEUM FIELDS OF MEXICO BETWEEN THE TAMESI AND TUXPAN RIVERS

BY I. C. WHITE

Presented in abstract without notes. Discussed by J. F. Kemp and F. W. De Wolff, with reply by the author.

Vice-President White resumed the chair.

INADEQUACY OF THE SAPROPELIC HYPOTHESIS OF THE ORIGIN OF COAL

BY EDWARD C. JEFFREY[1]

Presented in abstract without notes. Illustrated with lantern slides. Discussion was postponed to the session of Tuesday afternoon.

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[1] Introduced by David White.

The section adjourned at about 5.40 o'clock.

ANNUAL DINNER

The annual dinner of the Society was held at the Hotel Taft, about one hundred and thirty persons participating. James F. Kemp acted as chairman and toastmaster.

Session of Tuesday, December 31

The general session of the Society was called to order at 9.40 o'clock by President Fairchild, who, after some announcements had been made by the Secretary, called for the reading of scientific papers.

PRELIMINARY REPORT OF CERTAIN PHYSICAL AND PHYSICOCHEMICAL OBSERVATIONS AT THE KILAUEA CRATER

BY ARTHUR L. DAY

Presented in abstract without notes. Illustrated with lantern slides and specimens. Discussed by A. C. Lane, W. M. Davis, R. A. Daly, E. Howe, and J. P. Iddings, with reply by the author.

GEOLOGIC SECTION OF THE PANAMA CANAL ZONE

BY DONALD F. MAC DONALD[1]

Presented in abstract without notes. Illustrated with lantern slides. Discussed by J. F. Kemp and Ernest Howe.

GEOLOGICAL LIGHT FROM THE CATSKILL AQUEDUCT

BY CHARLES P. BERKEY

Presented in abstract without notes. Illustrated with lantern slides. Discussed by J. W. Spencer.

A CLASSIFICATION OF MARINE DEPOSITS

BY A. W. GRABAU

Presented in abstract without notes. Illustrated with diagrams. Discussed by A. C. Lane and Joseph Barrell.

EXTENDED DETERMINATION OF POST-GLACIAL EARTH MOVEMENTS FROM THE LAKE REGION TO THE SAINT LAWRENCE VALLEY

BY J. W. SPENCER

Presented in abstract from notes. Discussed by G. H. Chadwick, D. W. Johnson, F. Leverett, and W. M. Davis.

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[1] Introduced by James F. Kemp.

VOTE OF THANKS

Most cordial votes of thanks were passed to Yale University for the accommodations provided for the meeting; to the local committee of the Society for the thorough manner in which the details of preparation for the sessions had been attended to, and to the local Fellows for the delightful hospitality extended to the visitors.

The general session adjourned at 12.40 o'clock p. m.

TITLES OF PAPERS PRESENTED BEFORE THE COMBINED SECTIONS AND NAMES OF DISPUTANTS

The Society reconvened at 1.45 p. m. to consider the papers which had been passed over at previous sessions and to complete the reading of others. President Fairchild occupied the chair. Discussion of the paper by E. C. Jeffrey on the "Sapropelic Hypothesis of the Origin of Coal" was called for. There being no response, the President proceeded with the program.[1]

NATURE OF THE SUBSTANCE KNOWN AS MOTHER OF COAL AND ITS RELATION TO THE PROCESS OF COAL FORMATION

BY EDWARD C. JEFFREY[1]

Presented by title in the absence of the author.

POTTSVILLE-ALLEGHENY BOUNDARY IN THE INTERIOR PROVINCE (ILLINOIS AND MISSOURI COAL FIELDS)

BY DAVID WHITE

Presented by title in the absence of the author.

BIBLIOGRAPHY OF THE GEOLOGICAL AND GEOGRAPHICAL LITERATURE ON THE ANDEAN REPUBLIC OF SOUTH AMERICA

BY VERNON F. MARSTERS

Presented by title in the absence of the author.

ORIGIN OF THE HARD ROCK PHOSPHATES OF FLORIDA

BY E. H. SELLARDS

Presented by title in the absence of the author.

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[1] The papers which were passed over at the first call and not read at a later session have been entered "by title" in their original position in the program.

[1] Introduced by David White.

ALTERATION PROCESSES AND PRODUCTS WITHIN THE GRENVILLE LIMESTONE

BY A. A. JULIEN

Presented by title in the absence of the author.

NEW LIGHT ON THE KEWEENAWAN FAULT

BY A. C. LANE

Presented in abstract without notes. Illustrated with lantern slides. Discussed by J. B. Woodworth and E. Blackwelder, with reply by the author.

THE GREAT LAKE BASINS IN THEIR RELATIONSHIP TO THE NIAGARA LIMESTONE

BY J. W. SPENCER

Presented in abstract without notes.

GLACIAL EROSION IN THE GENESEE VALLEY SYSTEM AND ITS BEARING ON THE TERTIARY DRAINAGE PROBLEM OF EASTERN NORTH AMERICA

BY A. W. GRABAU

Presented in full without notes. Discussed by J. W. Spencer.

ROOTS IN THE UNDERCLAYS OF COAL

BY DAVID WHITE

Presented in abstract without notes. Discussed by J. B. Woodworth, I. C. White, D. F. MacDonald, and D. W. Johnson, with reply by the author.

OBJECTS AND METHODS OF PETROGRAPHIC DESCRIPTION

BY CHARLES P. BERKEY

Read in full from manuscript. Discussed by A. C. Lane, J. P. Iddings, and W. Cross.

The Society adjourned *sine die* at 3.30 o'clock p. m.

Register of the New Haven Meeting, 1912

FELLOWS

Frank D. Adams
Wallace W. Atwood
Joseph Barrell
George H. Barton
Florence Bascom
Ray Smith Bassler
William S. Bayley
Charles P. Berkey
Samuel W. Beyer
Eliot Blackwelder
R. W. Brock
Charles Wilson Brown
Fred Harvey Hall Calhoun
Marius R. Campbell
Ermine C. Case
William Bullock Clark
Herdman F. Cleland
George Halcott Chadwick
Arthur P. Coleman
Whitman Cross
Henry P. Cushing
Reginald A. Daly
Nelson H. Darton
William M. Davis
Arthur Louis Day
Frank Wilbridge De Wolf
Richard E. Dodge
Charles R. Eastman
Herman L. Fairchild
Clarence Norman Fenner
Cassius Asa Fisher
August F. Foerste
James Walter Goldthwait
Amadeus W. Grabau
Walter Granger
Herbert E. Gregory
Baird Halberstadt
Richard R. Hice
Edmund Otis Hovey
Ernest Howe
Ellsworth Huntington
Joseph P. Iddings
Robert T. Jackson
Douglas Wilson Johnson
George Frederick Kay
James F. Kemp
Edward M. Kindle
Frank H. Knowlton
Henry B. Kümmel
Alfred C. Lane
Frank Leverett
Joseph Volney Lewis
Frederick Brewster Loomis
Albert P. Low
Richard Swann Lull
George Rogers Mansfield
Edward B. Mathews
W. D. Matthew
Walter C. Mendenhall
George P. Merrill
Arthur M. Miller
Benjamin L. Miller
Willet G. Miller
William John Miller
Elwood S. Moore
Ida Helen Ogilvie
Sidney Paige
William A. Parks
Horace B. Patton
Frederick B. Peck
Richard A. F. Penrose
George H. Perkins
Olaf August Peterson
Louis V. Pirsson
Joseph Hyde Pratt
Albert Homer Purdue

Frederick Leslie Ransome
Percy Edward Raymond
Harry Fielding Reid
William North Rice
Heinrich Ries
Rudolph Ruedemann
Charles Schuchert
William B. Scott
Elias H. Sellards
Hervey Woodburn Shimer
William John Sinclair
Joseph T. Singewald
Eugene A. Smith
George Otis Smith
J. W. Spencer
Timothy William Stanton
John J. Stevenson
Edward O. Ulrich
Frank Robertson Van Horn
Gilbert van Ingen
Arthur Clifford Veatch
Thomas L. Walker
Walter Harvey Weed
Lewis G. Westgate
Henry S. Washington
David White
Israel C. White
George R. Wieland
Henry S. Williams
John E. Wolff
Jay B. Woodworth
Frederic E. Wright

FELLOWS-ELECT

Charles Butts
De Lorme D. Cairnes
William Harvey Emmons

OFFICERS, CORRESPONDENTS, AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1913

President:

Eugene A. Smith, University, Ala.

Vice-Presidents:

James F. Kemp, New York, N. Y.
R. D. Salisbury, Chicago, Ill.
C. D. Walcott, Washington, D. C.

Secretary:

Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.

Treasurer:

Wm. Bullock Clark, Baltimore, Md.

Editor:

J. Stanley-Brown, Coldspring Harbor, Long Island, N. Y.

Librarian:

H. P. Cushing, Cleveland, Ohio

Councillors:

(Term expires 1913)

A. H. Purdue, Fayetteville, Ark.
Heinrich Ries, Ithaca, N. Y.

(Term expires 1914)

S. W. Beyer, Ames, Iowa
Arthur Keith, Washington, D. C.

(Term expires 1915)

Whitman Cross, Washington, D. C.
Willet G. Miller, Toronto, Canada

MEMBERSHIP, 1913

CORRESPONDENTS

CHARLES BARROIS, Lille, France. December, 1909.
W. C. BRÖGGER, Christiania, Norway. December, 1909.
GIOVANNI CAPELLINI, Bologna, Italy. December, 1910.
HERMANN CREDNER, Leipzig, Germany. December, 1912.
BARON GERHARD DE GEER, Stockholm, Sweden. December, 1910.
SIR ARCHIBALD GEIKIE, Hasslemere, England. December, 1909.
ALBERT HEIM, Zürich, Switzerland. December, 1909.
EMANUEL KAYSER, Marburg, Germany. December, 1909.
W. KILIAN, Grenoble, France. December, 1912.
H. ROSENBUSCH, Heidelberg, Germany. December, 1910.
EDUARD SUESS, Vienna, Austria. December, 1909.
J. J. H. TEALL, London, England. December, 1912.
EMIL TIETZE, Vienna, Austria. December, 1910.
TH. TSCHERNYSCHEW, St. Petersburg, Russia. December, 1910.

FELLOWS

*Indicates Original Fellow (see article III of Constitution)

CLEVELAND ABBE, JR., U. S. Weather Bureau, Washington, D. C. August, 1899.
FRANK DAWSON ADAMS, McGill University, Montreal, Canada. Dec., 1889.
GEORGE I. ADAMS, Pei Yang University, Tientsin, China. December, 1902.
JOSÉ GUADALUPE AGUILERA, Instituto Geologico, Mexico, Mexico. Aug., 1896.
WILLIAM CLINTON ALDEN, U. S. Geological Survey, Washington, D. C. December, 1909.
TRUMAN H. ALDRICH, Birmingham, Ala. May, 1889.
R. C. ALLEN, State Geologist, Lansing, Mich. December, 1911.
HENRY M. AMI, Geological and Natural History Survey of Canada, Ottawa, Canada. December, 1889.
FRANK M. ANDERSON, State Mining Bureau, 2604 Ætna St., Berkeley, Cal. June, 1902.
ROBERT VAN VLECK ANDERSON, U. S. Geological Survey, Washington, D. C. December, 1911.
PHILIP ARGALL, First National Bank Building, Denver, Colo. August, 1896.
RALPH ARNOLD, 923 Union Oil Building, Los Angeles, Cal. December, 1904.
GEORGE HALL ASHLEY, Capitol Annex, Nashville, Tenn. August, 1895.
WALLACE WALTER ATWOOD, University of Chicago, Chicago, Ill. Dec., 1909.
RUFUS MATHER BAGG, JR., Lawrence College, Appleton, Wis. December, 1896.
HARRY FOSTER BAIN, 667 Howard St., San Francisco, Cal. December, 1895.
MANLEY BENSON BAKER, School of Mining, Kingston, Ontario. Dec., 1911.
S. PRENTISS BALDWIN, 2930 Prospect Ave., Cleveland, Ohio. August, 1895.
SYDNEY H. BALL, 71 Broadway, New York City. December, 1905.
ERWIN HINCKLEY BARBOUR, University of Nebraska, Lincoln, Neb. Dec., 1896.
ALFRED ERNEST BARLOW, 328 Roslyn Ave., Westmont, Montreal, Canada. December, 1906.
JOSEPH BARRELL, Yale University, New Haven, Conn. December, 1902.

George H. Barton, Boston Society of Natural History, Boston, Mass. August, 1890.

Florence Bascom, Bryn Mawr College, Bryn Mawr, Pa. August, 1894.

Ray Smith Bassler, U. S. National Museum, Washington, D. C. Dec., 1906.

Edson Sunderland Bastin, U. S. Geological Survey, Washington, D. C. December, 1909.

William S. Bayley, University of Illinois, Urbana, Ill. December, 1888.

***George F. Becker**, U. S. Geological Survey, Washington, D. C.

Joshua W. Beede, Indiana University, Bloomington, Ind. December, 1902.

Robert Bell, Geological Survey, Department of Mines, Ottawa, Canada. May, 1889.

Charles P. Berkey, Columbia University, New York, N. Y. August, 1901.

Edward Wilber Berry, Johns Hopkins University, Baltimore, Md. Dec., 1909.

Samuel Walker Beyer, Iowa Agricultural College, Ames, Iowa. Dec., 1896.

Arthur B. Bibbins, Goucher College, Baltimore, Md. December, 1903.

Albert S. Bickmore, 64th St. and Central Park West, New York, N. Y. December, 1889.

Eliot Blackwelder, University of Wisconsin, Madison, Wis. Dec., 1908.

John M. Boutwell, 1323 De la Vine St., Santa Barbara, Cal. Dec., 1905.

John Adams Bownocker, Ohio State University, Columbus, Ohio. Dec., 1904.

***John C. Branner**, Leland Stanford, Jr., University, Stanford University, Cal.

Edwin Bayer Branson, University of Missouri, Columbia, Mo. Dec., 1911.

Albert Perry Brigham, Colgate University, Hamilton, N. Y. December, 1893.

Reginald W. Brock, Geological Survey, Department of Mines, Ottawa, Canada. December, 1904.

Alfred Hulse Brooks, U. S. Geological Survey, Washington, D. C. Aug., 1899.

Amos P. Brown, University of Pennsylvania, Philadelphia, Pa. Dec., 1905.

Barnum Brown, American Museum of Natural History, New York, N. Y. December, 1910.

Charles Wilson Brown, Brown University, Providence, R. I. Dec., 1908.

Henry Andrew Buehler, Rolla, Mo. December, 1909.

Bert S. Butler, U. S. Geological Survey, Washington, D. C. December, 1912.

G. Montague Butler, School of Mines, Golden, Colo. December, 1911.

Charles Butts, U. S. Geological Survey, Washington, D. C. December, 1912.

De Lorme Donaldson Cairnes, Geological Survey Branch, Department of Mines, Ottawa, Canada. December, 1912.

Fred Harvey Hall Calhoun, Clemson College, S. C. December, 1909.

William Robert Calvert, U. S. Geological Survey, Washington, D. C. December, 1912.

Henry Donald Campbell, Washington and Lee University, Lexington, Va. May, 1889.

Marius R. Campbell, U. S. Geological Survey, Washington, D. C. Aug., 1892.

Stephen Reid Capps, Jr., U. S. Geological Survey, Washington, D. C. Dec., 1911.

Frank Carney, University of Michigan, Ann Arbor, Mich. December, 1908.

Ermine C. Case, University of Michigan, Ann Arbor, Mich. December, 1901.

George Halcott Chadwick, St. Lawrence University, Canton, N. Y. December, 1911.

***T. C. Chamberlin**, University of Chicago, Chicago, Ill.

Clarence Raymond Claghorn, Tacoma, Wash. August, 1891.
Frederick G. Clapp, 502 Fitzsimons Bldg., Pittsburgh, Pa. December, 1905.
*William Bullock Clark, Johns Hopkins University, Baltimore, Md.
John Mason Clarke, Albany, N. Y. December, 1897.
Herdman F. Cleland, Williams College, Williamstown, Mass. Dec., 1905.
J. Morgan Clements, Room 1707, 42 Broadway, New York City. Dec., 1894.
Collier Cobb, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
Arthur P. Coleman, Toronto University, Toronto, Canada. December, 1896.
George L. Collie, Beloit College, Beloit, Wis. December, 1897.
Arthur J. Collier, U. S. Geological Survey, Washington, D. C. June, 1902.
*Theodore B. Comstock, 827 Beacon St., Los Angeles, Cal.
Eugene Coste, 1943 11th St., West, Calgary, Alberta, Canada. Dec., 1906.
Alja Robinson Crook, State Museum of Natural History, Springfield, Ill. December, 1898.
*William O. Crosby, Massachusetts Institute of Technology, Boston, Mass.
Whitman Cross, U. S. Geological Survey, Washington, D. C. May, 1889.
Garry E. Culver, 1104 Wisconsin St., Stevens Point, Wis. December, 1891.
Edgar R. Cumings, Indiana University, Bloomington, Ind. August, 1901.
*Henry P. Cushing, Adelbert College, Cleveland, Ohio.
Reginald A. Daly, Harvard University, Cambridge, Mass. December, 1905.
Edward Salisbury Davis, Yale University, New Haven, Conn. Dec., 1908.
*Nelson H. Darton, U. S. Bureau of Mines, Washington, D. C.
Charles Albert Davis, U. S. Bureau of Mines, Washington, D. C. Dec., 1910.
*William M. Davis, Harvard University, Cambridge, Mass.
Arthur Louis Day, Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1909.
David T. Day, U. S. Geological Survey, Washington, D. C. August, 1891.
Bashford Dean, Columbia University, New York, N. Y. December, 1910.
Orville A. Derby, Serv. Geol. & Mineral. d'Brazil, Praia Vermillia, Rio de Janeiro, Brazil. December, 1890.
Frank Wilbridge De Wolf, Urbana, Ill. December, 1909.
*Joseph S. Diller, U. S. Geological Survey, Washington, D. C.
Edward V. d'Invilliers, 506 Walnut St., Philadelphia, Pa. December, 1888.
Richard E. Dodge, Teachers' College, New York, N. Y. August, 1897.
Noah Fields Drake, Fayetteville, Arkansas. December, 1898.
John Alexander Dresser, 10 Forest Ave., Saulte Ste. Marie, Ontario, Canada. December, 1906.
Charles R. Dryer, Indiana State Normal School, Terre Haute, Ind. August, 1897.
*Edwin T. Dumble, 1306 Main St., Houston, Texas.
Arthur S. Eakle, University of California, Berkeley, Cal. December, 1899.
Charles R. Eastman, Carnegie Museum, Pittsburgh, Pa. December, 1895.
Edwin C. Eckel, Munsey Building, Washington, D. C. December, 1905.
Arthur H. Elftman, P. O. Box 601, Tonopah, Nev. December, 1898.
*Benjamin K. Emerson, Amherst College, Amherst, Mass.
William Harvey Emmons, University of Minnesota, Minneapolis, Minn. December, 1912.
John Eyerman, Oakhurst, Easton, Pa. August, 1891.
Harold W. Fairbanks, Berkeley, Cal. August, 1892.
*Herman L. Fairchild, University of Rochester, Rochester, N. Y.

Oliver C. Farrington, Field Museum of Natural History, Chicago, Ill. December, 1895.

Nevin M. Fenneman, University of Cincinnati, Cincinnati, Ohio. Dec., 1904.

Clarence Norman Fenner, Geophysical Laboratory, Washington, D. C. December, 1911.

Cassius Asa Fisher, 711 Ideal Building, Denver, Colo. December, 1908.

August F. Foerste, Steele High School, Dayton, Ohio. December, 1899.

William M. Fontaine, University of Virginia, Charlottesville, Va. Dec., 1888.

Myron Leslie Fuller, 185 Spring St., Brockton, Mass. December, 1898.

Henry Stewart Gane, Santa Barbara, Cal. December, 1896.

James H. Gardner, Kentucky Geological Survey, Lexington, Ky. Dec., 1911.

Russell D. George, University of Colorado, Boulder, Colo. December, 1906.

*Grove K. Gilbert, U. S. Geological Survey, Washington, D. C.

Adam Capen Gill, Cornell University, Ithaca, N. Y. December, 1888.

L. C. Glenn, Vanderbilt University, Nashville, Tenn. June, 1900.

James Walter Goldthwait, Dartmouth College, Hanover, N. H. Dec., 1909.

Charles H. Gordon, University Library, University of Tennessee, Knoxville, Tenn. August, 1893.

Charles Newton Gould, University of Oklahoma, Norman, Okla. Dec., 1904.

Amadeus W. Grabau, Columbia University, New York, N. Y. December, 1898.

Walter Granger, American Museum of Natural History, New York, N. Y. December, 1911.

Ulysses Sherman Grant, Northwestern University, Evanston, Ill. Dec., 1890.

John Sharshall Grasty, University of Virginia, University, Va. Dec., 1911.

Herbert E. Gregory, Yale University, New Haven, Conn. August, 1901.

George P. Grimsley, Geological Survey of West Virginia, Martinsburg, W. Va. August, 1895.

Leon S. Griswold, Plymouth, Mass. August, 1902.

Frederic P. Gulliver, Norwichtown, Conn. August, 1895.

Arnold Hague, U. S. Geological Survey, Washington, D. C. May, 1889.

Baird Halberstadt, Pottsville, Pa. December, 1909.

Gilbert D. Harris, Cornell University, Ithaca, N. Y. December, 1903.

John Burchmore Harrison, Georgetown, British Guiana. June, 1902.

John B. Hastings, 1480 High St., Denver, Colo. May, 1889.

*Erasmuth Haworth, University of Kansas, Lawrence, Kans.

C. Willard Hayes, Compania Mexicana de Petroleo "El Aguila," Tampico, Mexico. May, 1889.

Oscar H. Hershey, Kellogg, Idaho. December, 1909.

Richard R. Hice, Beaver, Pa. December, 1903.

Frank A. Hill, 1315 Mahantango St., Pottsville, Pa. May, 1889.

*Robert T. Hill, 25 Broad St., New York, N. Y.

Richard C. Hills, Denver, Colo. August, 1894.

Henry Hinds, U. S. Geological Survey, Washington, D. C. December, 1912.

*Charles H. Hitchcock, Honolulu, Hawaiian Islands.

William Herbert Hobbs, University of Michigan, Ann Arbor, Mich. August, 1891.

*Levi Holbrook, P. O. Box 536, New York, N. Y.

William Jacob Holland, Carnegie Museum, Pittsburgh, Pa. December, 1910.

Arthur Hollick, New York Botanical Garden, Bronx Park, New York City. August, 1893.

*Joseph A. Holmes, U. S. Bureau of Mines, Washington, D. C.
Thomas C. Hopkins, Syracuse University, Syracuse, N. Y. December, 1894.
William Otis Hotchkiss, State Geologist, Madison, Wis. December, 1911.
*Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.
*Horace C. Hovey, Newburyport, Mass.
Ernest Howe, 75 Kay St., Newport, R. I. December, 1903.
Lucius L. Hubbard, Houghton, Mich. December, 1894.
Ellsworth Huntington, Yale University, New Haven, Conn. Dec., 1906.
Louis Hussakof, American Museum of Natural History, New York, N. Y. December, 1910.
Joseph P. Iddings, Brinklow, Md. May, 1889.
John D. Irving, Yale University, New Haven, Conn. December, 1905.
A. Wendell Jackson, 432 Saint Nicholas Ave., New York, N. Y. Dec., 1888.
Robert T. Jackson, 56 Bay State Road, Boston, Mass. August, 1894.
Thomas Augustus Jaggar, Jr., Hawaiian Volcano Observatory, Territory of Hawaii, U. S. A. December, 1906.
Mark S. W. Jefferson, Michigan State Normal College, Ypsilanti, Mich. December, 1904.
Albert Johannsen, University of Chicago, Chicago, Ill. December, 1908.
Douglas Wilson Johnson, Columbia University, New York, N. Y. Dec., 1906.
Alexis A. Julien, South Harwich, Mass. May, 1889.
Frank James Katz, U. S. Geological Survey, Washington, D. C. Dec., 1912.
George Frederick Kay, State University of Iowa, Iowa City, Iowa. Dec., 1908.
Arthur Keith, U. S. Geological Survey, Washington, D. C. May, 1889.
*James F. Kemp, Columbia University, New York, N. Y.
Charles Rollin Keyes, 944 Fifth St., Des Moines, Iowa. August, 1890.
Edward M. Kindle, Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
Edwin Kirk, U. S. Geological Survey, Washington, D. C. December, 1912.
Cyril Workman Knight, Toronto, Ontario, Canada. December, 1911.
Adolph Knopf, U. S. Geological Survey, Washington, D. C. December, 1911.
Frank H. Knowlton, U. S. National Museum, Washington, D. C. May, 1889.
Edward Henry Kraus, University of Michigan, Ann Arbor, Mich. June, 1902.
Henry B. Kümmel, Trenton, N. J. December, 1895.
*George F. Kuntz, 401 Fifth Ave., New York, N. Y.
George Edgar Ladd, Wilburton, Okla. August, 1891.
Laurence La Forge, U. S. National Museum, Washington, D. C. Dec., 1912.
Lawrence Morris Lambe, Department of Mines, Ottawa, Canada. Dec., 1911.
Henry Landes, University of Washington, University Station, Seattle, Wash. December, 1908.
Alfred C. Lane, Tufts College, Mass. December, 1889.
Andrew C. Lawson, University of California, Berkeley, Cal. May, 1889.
Willis Thomas Lee, U. S. Geological Survey, Washington, D. C. Dec., 1903.
Charles K. Leith, University of Wisconsin, Madison, Wis. Dec., 1902.
Arthur G. Leonard, State University of North Dakota, Grand Forks, N. Dak. December, 1901.
Frank Leverett, Ann Arbor, Mich. August, 1890.
Joseph Volney Lewis, Rutgers College, New Brunswick, N. J. Dec., 1906.
William Libbey, Princeton University, Princeton, N. J. August, 1899.
Waldemar Lindgren, Massachusetts Institute of Technology, Boston, Mass. August, 1890.

Frederick Brewster Loomis, Amherst College, Amherst, Mass. Dec., 1909.
George Davis Louderback, University of California, Berkeley, Cal. June, 1902.
Robert H. Loughridge, University of California, Berkeley, Cal. May, 1889.
Albert P. Low, Department of Mines, Ottawa, Canada. December, 1905.
Richard Swann Lull, Yale University, New Haven, Conn. December, 1909.
Samuel Washington McCallie, Atlanta, Ga. December, 1909.
Hiram Deyer McCaskey, U. S. Geological Survey, Washington, D. C. December, 1904.
Richard G. McConnell, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.
James Rieman Macfarlane, Woodland Road, Pittsburgh, Pa. August, 1891.
William McInnes, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.
Peter McKellar, Fort William, Ontario, Canada. August, 1890.
George Rogers Mansfield, Northwestern University, Evanston, Ill. Dec., 1909.
Curtis F. Marbut, State University, Columbia, Mo. August, 1897.
Vernon F. Marsters, San Juancito, Honduras, C. A. August, 1892.
George Curtis Martin, U. S. Geological Survey, Washington, D. C. June, 1902.
Lawrence Martin, University of Wisconsin, Madison, Wis. December, 1909.
Edward B. Mathews, Johns Hopkins University, Baltimore, Md. Aug., 1895.
W. D. Matthew, American Museum of Natural History, New York, N. Y. December, 1903.
P. H. Mell, 165 East 10th St., Atlanta, Ga. December, 1888.
Walter C. Mendenhall, U. S. Geological Survey, Washington, D. C. June, 1902.
John C. Merriam, University of California, Berkeley, Cal. August, 1895.
*Frederick J. H. Merrill, 624 Citizens' National Bank Bldg., Los Angeles, Cal.
George P. Merrill, U. S. National Museum, Washington, D. C. Dec., 1888.
Arthur M. Miller, State University of Kentucky, Lexington, Ky. Dec., 1897.
Benjamin L. Miller, Lehigh University, South Bethlehem, Pa. Dec., 1904.
Willet G. Miller, Toronto, Canada. December, 1902.
William John Miller, Hamilton College, Clinton, N. Y. December, 1909.
Fred Howard Moffit, U. S. Geological Survey, Washington, D. C. Dec., 1912.
Henry Montgomery, University of Toronto, Toronto, Canada. Dec., 1904.
Elwood S. Moore, Pennsylvania State College, State College, Pa. Dec., 1911.
Malcolm John Munn, U. S. Geological Survey, Washington, D. C. Dec., 1909.
*Frank L. Nason, West Haven, Conn.
David Hale Newland, Albany, N. Y. December, 1906.
John F. Newsom, Leland Stanford, Jr., University, Stanford University, Cal. December, 1899.
William H. Norton, Cornell College, Mount Vernon, Iowa. December, 1895.
Charles J. Norwood, State University, Lexington, Ky. August, 1894.
Ida Helen Ogilvie, Barnard College, Columbia University, New York, N. Y. December, 1906.
Cleophas C. O'Harra, South Dakota School of Mines, Rapid City, S. Dak. December, 1904.
Daniel Webster Ohern, University of Oklahoma, Norman, Okla. Dec., 1911.
Ezequiel Ordonez, 2 a General Prim 43, Mexico, D. F., Mex. August, 1896.
Edward Orton, Jr., Geological Survey of Ohio, Columbus, Ohio. Dec., 1909.

Henry F. Osborn, American Museum of Natural History, New York, N. Y. August, 1894.

Sidney Paige, U. S. Geological Survey, Washington, D. C. December, 1911.

Charles Palache, Harvard University, Cambridge, Mass. August, 1897.

William A. Parks, University of Toronto, Toronto, Canada. December, 1906.

*Horace B. Patton, Colorado School of Mines, Golden, Colo.

Frederick B. Peck, Lafayette College, Easton, Pa. August, 1901.

Richard A. F. Penrose, Jr., 460 Bullitt Bldg., Philadelphia, Pa. May, 1889.

George H. Perkins, University of Vermont, Burlington, Vt.; State Geologist. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

Olaf August Peterson, Carnegie Museum, Pittsburgh, Pa. December, 1910.

William Clifton Phalen, U. S. Geological Survey, Washington, D. C. December, 1912.

Louis V. Pirsson, Yale University, New Haven, Conn. August, 1894.

Joseph E. Pogue, U. S. National Museum, Washington, D. C. Dec., 1911.

Joseph Hyde Pratt, North Carolina Geological Survey, Chapel Hill, N. C. December, 1898.

Louis M. Prindle, U. S. Geological Survey, Washington, D. C. Dec., 1912.

*Charles S. Prosser, Ohio State University, Columbus, Ohio.

William Frederick Prouty, University of Alabama, University, Ala. December, 1911.

*Raphael Pumpelly, Newport, R. I.

Albert Homer Purdue, State Geological Survey, Nashville, Tenn. Dec., 1904.

Frederick Leslie Ransome, U. S. Geological Survey, Washington, D. C. August, 1895.

Percy Edward Raymond, Museum of Comparative Zoölogy, Cambridge, Mass December, 1907.

Harry Fielding Reid, Johns Hopkins University, Baltimore, Md. Dec., 1892.

William North Rice, Wesleyan University, Middletown, Conn. August, 1890.

John Lyon Rich, University of Illinois, Urbana, Ill. December, 1912.

Charles H. Richardson, Syracuse University, Syracuse, N. Y. Dec., 1899.

George Burr Richardson, U. S. Geological Survey, Washington, D. C. December, 1908.

Heinrich Ries, Cornell University, Ithaca, N. Y. December, 1893.

Elmer S. Riggs, Field Museum of Natural History, Chicago, Ill. Dec., 1911.

Jesse Perry Rowe, University of Montana, Missoula, Mont. December, 1911.

Rudolph Ruedemann, Albany, N. Y. December, 1905.

John Joseph Rutledge, Experiment Station, Pittsburgh, Pa. Dec., 1911.

Orestes H. St. John, 1141 Twelfth St., San Diego, Cal. May, 1889.

*Rollin D. Salisbury, University of Chicago, Chicago, Ill.

Frederick W. Sardeson, University of Minnesota, Minneapolis, Minn. December, 1892.

Thomas Edmund Savage, University of Illinois, Urbana, Ill. December, 1907.

Frank C. Schrader, U. S. Geological Survey, Washington, D. C. Aug., 1901.

Charles Schuchert, Yale University, New Haven, Conn. August, 1895.

Alfred Reginald Schultz, U. S. Geological Survey, Washington, D. C. December, 1912.

William B. Scott, Princeton University, Princeton, N. J. August, 1892.

Arthur Edmund Seaman, Michigan College of Mines, Houghton, Mich. December, 1904.

Henry M. Seely, Middlebury College, Middlebury, Vt. May, 1889.
Elias H. Sellards, Tallahassee, Fla. December, 1905.
Joaquim Candido da Costa Seña, State School of Mines, Ouro Preto, Brazil. December, 1908.
George Burbank Shattuck, Vassar College, Poughkeepsie, N. Y. Aug., 1899.
Eugene Wesley Shaw, U. S. Geological Survey, Washington, D. C. Dec., 1912.
Solon Shedd, State College of Washington, Pullman, Wash. Dec., 1904.
Edward M. Shepard, 1403 Benton Ave., Springfield, Mo. August, 1901.
Will H. Sherzer, State Normal School, Ypsilanti, Mich. December, 1890.
Bohumil Shimek, University of Iowa, Iowa City, Iowa. December, 1904.
Hervey Woodburn Shimer, Massachusetts Institute of Technology, Boston, Mass. December, 1910.
Claude Ellsworth Siebenthal, U. S. Geological Survey, Washington, D. C. December, 1912.
*Frederick W. Simonds, University of Texas, Austin, Texas.
William John Sinclair, Princeton University, Princeton, N. J. Dec., 1906.
Joseph Theophilus Singewald, Johns Hopkins University, Baltimore, Md. December, 1911.
Earle Sloan, Charleston, S. C. December, 1908.
Burnett Smith, Syracuse University, Skaneateles, N. Y. December, 1911.
Carl Smith, U. S. Geological Survey, Washington, D. C. December, 1912.
*Eugene A. Smith, University of Alabama, University, Ala.
George Otis Smith, U. S. Geological Survey, Washington, D. C. Aug., 1897.
Philip S. Smith, U. S. Geological Survey, Washington, D. C. Dec., 1909.
Warren Du Pré Smith, Mining Bureau, Manila, Philippine Islands. December, 1909.
W. S. Tangier Smith, 2626 Haste St., Berkeley, Cal. June, 1902.
*John C. Smock, Trenton, N. J.
Charles H. Smyth, Jr., Princeton University, Princeton, N. J. Aug., 1892.
Henry L. Smyth, Harvard University, Cambridge, Mass. August, 1894.
Arthur Coe Spencer, U. S. Geological Survey, Washington, D. C. Dec., 1896.
*J. W. Spencer, 2019 Hillyer Place, Washington, D. C.
Frank Springer, U. S. National Museum, Washington, D. C. December, 1911.
Josiah E. Spurr, 165 Broadway, New York, N. Y. December, 1894.
Joseph Stanley-Brown, Coldspring Harbor, Long Island, N. Y. Aug., 1892.
Timothy William Stanton, U. S. National Museum, Washington, D. C. August, 1891.
Clinton Raymond Stauffer, Western Reserve University, Cleveland, Ohio. December, 1911.
Lloyd William Stephenson, U. S. Geological Survey, Washington, D. C. December, 1911.
*John J. Stevenson, 215 West 101st St., New York, N. Y.
Ralph Walter Stone, U. S. Geological Survey, Washington, D. C. Dec., 1912.
George Willis Stose, U. S. Geological Survey, Washington, D. C. Dec., 1908.
William J. Sutton, Victoria, B. C. August, 1901.
Charles Kephart Swartz, Johns Hopkins University, Baltimore, Md. December, 1908.
Joseph A. Taff, 712 Flood Building, San Francisco, Cal. August, 1895.
James E. Talmage, University of Utah, Salt Lake City, Utah. Dec., 1897.
Frank B. Taylor, Fort Wayne, Ind. December, 1895.

*James E. Todd, 1224 Rhode Island St., Lawrence, Kans.

Cyrus Fisher Tolman, Jr., University of Arizona, Tucson, Ariz. Dec., 1909.

*Henry W. Turner, Room 709 Mills Building, San Francisco, Cal.

Mayville William Twitchell, State Geological Survey, Trenton, N. J. December, 1911.

Joseph B. Tyrrell, Room 534, Confederation Life Building, Toronto, Canada. May, 1889.

Johan A. Udden, University of Texas, Austin, Texas. August, 1897.

Edward O. Ulrich, U. S. Geological Survey, Washington, D. C. Dec., 1903.

*Warren Upham, Minnesota Historical Society, Saint Paul, Minn.

*Charles R. Van Hise, University of Wisconsin, Madison, Wis.

Frank Robertson Van Horn, Case School of Applied Science, Cleveland, Ohio. December, 1898.

Gilbert van Ingen, Princeton University, Princeton, N. J. December, 1904.

Thomas Wayland Vaughan, U. S. Geological Survey, Washington, D. C. August, 1896.

Arthur Clifford Veach, 47 Parliament St., S. W., London, England. Dec., 1906.

*Anthony W. Vogdes, 2425 First St., San Diego, Cal.

*M. Edward Wadsworth, School of Mines, University of Pittsburgh, Pittsburgh, Pa.

*Charles D. Walcott, Smithsonian Institution, Washington, D. C.

Thomas L. Walker, University of Toronto, Toronto, Canada. Dec., 1903.

Charles H. Warren, Massachusetts Institute of Technology, Boston, Mass. December, 1901.

Henry Stephens Washington, Locust, Monmouth County, N. J. Aug., 1896.

Thomas L. Watson, University of Virginia, Charlottesville, Va. June, 1900.

Walter H. Weed, 42 Broadway, New York, N. Y. May, 1889.

Carroll Harvey Wegemann, U. S. Geological Survey, Washington, D. C. December, 1912.

Samuel Weidman, Wisconsin Geological and Natural History Survey, Madison, Wis. December, 1903.

Stuart Weller, University of Chicago, Chicago, Ill. June, 1900.

Lewis G. Westgate, Ohio Wesleyan University, Delaware, Ohio.

David White, U. S. National Museum, Washington, D. C. May, 1889.

*Israel C. White, Morgantown, W. Va.

George Reber Wieland, Yale University, New Haven, Conn. December, 1910.

Frank A. Wilder, North Holston, Smyth County, Va. December, 1905.

*Edward H. Williams, Jr., Woodstock, Vt.

*Henry S. Williams, Cornell University, Ithaca, N. Y.

Ira A. Williams, Iowa State College, Ames, Iowa. December, 1905.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

Samuel W. Williston, University of Chicago, Chicago, Ill. December, 1889.

Arthur B. Wilmott, 404 Lumsden Building, Toronto, Canada. Dec., 1899.

Alfred W. G. Wilson, Department of Mines, Ottawa, Canada. June, 1902.

Alexander N. Winchell, University of Wisconsin, Madison, Wis. Aug., 1901.

*Horace Vaughn Winchell, 505 Palace Building, Minneapolis, Minn.

*Newton H. Winchell, 501 East River Road, Minneapolis, Minn.

*Arthur Winslow, 131 State St., Boston, Mass.

John E. Wolff, Harvard University, Cambridge, Mass. December, 1889.

Joseph E. Woodman, New York University, New York, N. Y. Dec., 1905.

Robert S. Woodward, Carnegie Institution of Washington, Washington, D. C. May, 1889.

Jay B. Woodworth, Harvard University, Cambridge, Mass. December, 1895.

Charles Will Wright, Ingurtosu, Arbus, Sardinia, Italy. December, 1909.

Frederic E. Wright, Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1903.

***G. Frederick Wright**, Oberlin Theological Seminary, Oberlin, Ohio.

George A. Young, Geological Survey of Canada, Ottawa, Canada. Dec., 1905.

CORRESPONDENTS DECEASED

A. Michel-Lévy. Died September, 1911.

Ferdinand Zerkel. Died June 11, 1912.

FELLOWS DECEASED

*Indicates Original Fellow (see article III of Constitution)

***Charles A. Ashburner.** Died December 24, 1889.
Charles E. Beecher. Died February 14, 1904.
William Phipps Blake. Died May 21, 1910.
Amos Bowman. Died June 18, 1894.
Ernest Robertson Buckley. Died January 19, 1912.
***Samuel Calvin.** Died April 17, 1911.
Franklin R. Carpenter. Died April 1, 1910.
***J. H. Chapin.** Died March 14, 1892.
***Edward W. Claypole.** Died August 17, 1901.
George H. Cook. Died September 22, 1889.
***Edward D. Cope.** Died April 12, 1897.
Antonio Del Castillo. Died October 28, 1895.
***James D. Dana.** Died April 14, 1895.
George M. Dawson. Died March 2, 1901.
Sir J. William Dawson. Died November 19, 1899.
Clarence Edward Dutton. Died January 4, 1912.
***William B. Dwight.** Died August 29, 1906.
***George H. Eldridge.** Died June 29, 1905.
***Samuel F. Emmons.** Died March 28, 1911.
***Albert E. Foote.** Died October 10, 1895.
***Persifor Frazer.** Died April 7, 1909.
***Homer T. Fuller.** Died August 14, 1908.
N. J. Giroux. Died November 30, 1890.
***Christopher W. Hall.** Died May 10, 1911.
***James Hall.** Died August 7, 1898.
John B. Hatcher. Died July 3, 1904.
***Robert Hay.** Died December 14, 1895.
***Angelo Heilprin.** Died July 17, 1907.
David Honeyman. Died October 17, 1889.
***Edwin E. Howell.** Died April 16, 1911.
Thomas Sterry Hunt. Died February 12, 1892.
***Alpheus Hyatt.** Died January 15, 1902.
Thomas M. Jackson. Died February 3, 1912.
***Joseph F. James.** Died March 29, 1897.

Wilbur C. Knight. Died July 28, 1903.
Ralph D. Lacoe. Died February 5, 1901.
J. C. K. Laflamme. Died July 6, 1910.
Daniel W. Langton. Died June 21, 1909.
*Joseph Le Conte. Died July 6, 1901.
*J. Peter Lesley. Died June 2, 1903.
Henry McCalley. Died November 20, 1904.
*W J McGee. Died September 4, 1912.
Oliver Marcy. Died March 19, 1899.
Othniel C. Marsh. Died March 18, 1899.
James E. Mills. Died July 25, 1901.
*Henry B. Nason. Died January 17, 1895.
*Peter Neff. Died May 11, 1903.
*John S. Newberry. Died December 7, 1892.
William H. Niles. Died September 12, 1910.
*Edward Orton. Died October 16, 1899.
*Amos O. Osborn. Died March, 1911.
*Richard Owen. Died March 24, 1890.
Samuel L. Penfield. Died August 14, 1906.
David Pearce Penhallow. Died October 20, 1910.
*Franklin Platt. Died July 24, 1900.
William H. Pettee. Died May 26, 1904.
*John Wesley Powell. Died September 23, 1902.
*Israel C. Russell. Died May 1, 1906.
*James M. Safford. Died July 3, 1907.
*Charles Schaeffer. Died November 23, 1903.
*Nathaniel S. Shaler. Died April 10, 1906.
Ralph S. Tarr. Died March 21, 1912.
William G. Tight. Died January 15, 1910.
Charles Wachsmuth. Died February 7, 1896.
Thomas C. Weston. Died July 20, 1910.
Theodore G. White. Died July 7, 1901.
*George H. Williams. Died July 12, 1894.
*Robert P. Whitfield. Died April 6, 1910.
*J. Francis Williams. Died September 9, 1891.
*Alexander Winchell. Died February 19, 1891.
Albert A. Wright. Died April 2, 1905.
William S. Yeates. Died February 19, 1908.

Summary

Correspondents	14
Original Fellows	48
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[1] Vol. 23, p. 68, 4th line from bottom, should have read 298 instead of 299.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 24, PP. 91-98 MARCH 24, 1913

PROCEEDINGS OF THE THIRTEENTH ANNUAL MEETING OF THE CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT STANFORD UNIVERSITY, CALIFORNIA, APRIL 5, 1912.

GEORGE D. LOUDERBACK, *Secretary*

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SESSION OF FRIDAY, APRIL 5

The thirteenth annual meeting of the Cordilleran Section was held in conjunction with the Pacific Association of Scientific Societies at Stanford University, April 5, 1912. The first session was called to order at

10.15 a. m., in room 334, Geology Building, by the chairman of the section, Prof. A. C. Lawson.

The minutes of the twelfth annual meeting were read and approved.

RESOLUTIONS CONCERNING NOMINATIONS AND TENURE OF OFFICE

The Secretary introduced two motions concerning nominations and tenures of office of the section officers, and they were adopted without dissenting vote, as follows:

1. At the time of sending the preliminary notices of the annual meeting, the secretary of the section shall call for nominations for section offices, which members of the section may send in by mail. From the nominations so received a ticket shall be made and presented at the annual meeting.

2. Officers elected at any annual meeting shall be considered elected for the year following the meeting, including the annual meeting held at the end of that year. In other words, change of officers takes place after the annual meeting, and not during it.

ELECTION OF OFFICERS

The section then balloted for officers for the year 1912-1913, Prof. A. S. Eakle and the Secretary being appointed by the chair a committee of election to count and report the votes.

The following officers were elected:

J. C. Branner, Chairman.
G. D. Louderback, Secretary.
W. S. Tangier Smith, Councillor.

REPRESENTATION ON THE COUNCIL

The Secretary read a communication from the general secretary concerning the representation of the section on the council.

There being no further business, the scientific program was taken up, and the following papers were presented in the order given:

DUST STORMS IN CHINA

BY N. F. DRAKE

(Abstract)

Distribution of the dust storms and their characteristics and modes of occurrence. Present and past distribution of the transported materials. Some

observations for quantitative estimates of material transported and rates of deposition. Some comparisons with work done by rivers.

Presented with occasional reference to manuscript. Discussion by Taff.

COAL RESOURCES OF CHINA

BY N. F. DRAKE

(*Abstract*)

Varieties of the coal and their geologic and geographic distributions. Outlines of the more important coal fields, with some estimates of the thickness of included coal beds.

Presented with manuscript, outline, and map. Discussion by Lawson and Louderback.

GEOLOGICAL SECTION OF A PORTION OF THE COAST RANGES IN THE EASTERN PART OF SAN LUIS OBISPO COUNTY, CALIFORNIA

BY BRUCE MARTIN

(*Abstract*)

A discussion of the early and late Neocene deposits of that region, including horizons corresponding to Temblor, Monterey shale, Santa Margarita, and Tulare or Paso Robles formations. The sequence of marine beds are apparently conformable from the base of the Temblor to the upper part of the Santa Margarita. The brackish and fresh water Tulare (?) or Paso Robles (?) formation overlies unconformably the Santa Margarita. Remnants provisionally grouped with Paso Robles (?) rest horizontally on tilted Monterey and lower Santa Margarita.

Presented in abstract from notes. Discussion by Gester and Louderback.

VALIDITY OF THE LAW OF RATIONAL INDICES OF CRYSTAL FACES

BY AUSTIN F. ROGERS

(*Abstract*)

Are the indices of crystal faces whole numbers or simple whole numbers, or is there any meaning to the law of rational indices? On the assumption that only two, three, four, and six fold axes of symmetry are possible, it may be proved that the indices of crystal faces are whole numbers, but not necessarily simple whole numbers. There is a remarkable analogy between the fundamental laws of crystallography and chemistry.

Presented in abstract from notes; illustrated by diagrams. Discussion by Louderback and Eakle.

The meeting then adjourned for lunch, reassembled, and was called to order at 2 p. m., and the following papers were presented:

GYPSUM AND ANHYDRITE FROM THE LUDWIG MINE, LYON COUNTY, NEVADA

BY AUSTIN F. ROGERS

(*Abstract*)

At the Ludwig copper mine in eastern Nevada a large gypsum deposit outcrops on the surface. On the 400-foot level gypsum and anhydrite occur side by side. The gypsum has been formed from the anhydrite by hydration. The anhydrite was probably formed by the evaporation of a closed basin or arm of the sea.

Presented without notes; illustrated by diagrams. Discussion by J. C. Jones, who suggested that the anhydrite was probably formed from original gypsum at the time of the intrusion of the granodiorite. Further discussion by Louderback and Weber.

TRACHYTIC PERLITE FROM LONE HILL, NEAR SAN JOSÉ, CALIFORNIA

BY G. E. POSTMA

(*Abstract*)

A dark-gray perlite vitrophyre makes up a low dome-shaped hill about half way between San José and New Almaden. This rock contains about 70 per cent of silica, and on account of the absence of quartz it is classed as trachyte. Its place in the quantitative system will be determined by a chemical analysis.

Presented from manuscript, and illustrated by drawings.

FLUTING OF CRYSTALLINE ROCKS IN THE TROPICS

BY J. C. BRANNER

(*Abstract*)

Photographs of the Serra Riscada and of other peaks in the interior of the State of Ceará, Brazil, show fluting on a gigantic scale. The rocks are homogeneous crystalline rocks resembling coarse-grained granodiorites. The region is hot and arid and the rainfall highly concentrated.

Presented without notes. Discussion by Lawson, and further discussion by Branner.

INFLUENCE OF WIND ON THE ACCUMULATION OF OIL-BEARING ROCKS

BY J. C. BRANNER

(*Abstract*)

Marine diatoms appear to have been the source of the petroleum and allied deposits of California. The diatomaceous shales of California are not strictly

confined to any one geological horizon, but they are especially abundant in the Tertiary, where they form the Monterey beds, which are often composed almost entirely of the siliceous skeletons of diatoms.

Botanical works furnish only scanty information in regard to the life history of the marine diatoms. It is generally agreed that they thrive best in cold seas; that most of them live near the surface of the water and in the littoral zone. As these organisms perish their siliceous skeletal remains sink slowly to the bottom, especially in those places where the currents are not strong enough to sweep them along. In this connection attention is directed to the geography of the coast of California during the geologic period, when our greatest deposits of diatomaceous shales were being laid down. The geology of California suggests that the region of the present coast ranges was an archipelago, separating the sea that filled the great valley on the east from the open ocean on the west. The marine currents that flowed southward from Alaska brought down great quantities of marine algæ, the diatoms floating as usual near the surface. Once within the zone of islands these floating materials were probably driven into the cul-de-sac at the lower or southern end of the present San Joaquin Valley, where the granite mountains of the sierras bend westward and northwestward. Here the prevailing winds of the region are from the north during the greater part of the year, and materials carried at or near the surface of the water could not escape if, as is assumed, the embayment was fairly well closed at the extreme southern end. It is exactly here, at and around the southwestern corner of the San Joaquin Valley, that the deposits of diatom skeletons are thickest. The total thickness of these shales is here more than 5,000 feet. In general these diatomaceous shales thin out toward the north and are inconspicuous in the geology north of San Francisco.

It is not to be expected that the theory here put forward to explain accumulation under the circumstances mentioned is competent to account for all diatomaceous deposits and much less for all deposits of petroleum. Even in this instance it is evident that all of the diatoms were not caught in the angle of the coast; some of them were never carried to the landward of the coast archipelago, while others escaped to sink farther down the coast.

It is believed, however, that the prevailing winds, in this instance at least, have been an important factor in the accumulation of the oil-bearing deposits.

On the west coast of South America there are petroleum deposits from Payta, Peru, northward to the cape west of Guyaquil. The near-shore currents of the Pacific here flow from the cold antarctic regions northward, and it seems probable that the petroleum deposits of Peru and Equador may have originated in some such manner as that suggested above.

An attempt has been made to apply the theory to the explanation of petroleum deposits of marine origin in other parts of the world, but a lack of knowledge of all the circumstances has thus far prevented progress.

Presented without notes.

GENERAL GEOLOGY OF THE SAN JOSÉ AND MOUNT HAMILTON QUADRANGLES

BY E. C. TEMPLETON

(*Abstract*)

The oldest exposed rocks on the San José and Mount Hamilton quadrangles belong to the Franciscan series and consist of sandstones and shales, with an occasional bed of heavy conglomerate; of jaspers and of the typical metamorphics (glaucophane schist and gneiss and greenstone), which occur in small, widely distributed areas. A large proportion of the sandstones and shales are schistose in appearance, although considerable areas of unaltered portions of these beds exist. The total thickness of the Franciscan series represented is between 15,000 and 20,000 feet. This series occurs principally east of the Calaveras-Sunol fault.

The Knoxville beds overlie the Franciscan unconformably. They consist of shale, conglomerate, and sandstone, carrying *Aucella piochi* and *Aucella crassicollis*. Their total thickness is about 10,000 feet.

The lowest Miocene sandstone belongs to the Temblor phase of the Monterey series and rests unconformably on the Franciscan, the Knoxville beds being here lacking. It has an abundant fauna, typically Temblor. Its thickness is about 1,000 feet. Overlying it is the Monterey shale, hard, light-colored, and siliceous, with a thickness of about 1,200 feet. West of the Calaveras-Sunol fault this shale rests unconformably on the Knoxville, with the Lower Miocene sandstone beds lacking.

The Monterey shale is overlaid, apparently conformably, by a thickness of about 3,500 feet of sandstone, with a typical Temblor fauna. Above this, with a slight unconformity separating them, is a red conglomerate, with a thickness of 1,800 feet. It is doubtfully Santa Margarita.

A great unconformity separates the earlier beds from the fresh-water Santa Clara beds, which have a wide distribution west of the Calaveras-Sunol fault.

The mountains of the San José and Mount Hamilton quadrangles are highly folded and considerably faulted. The Calveras-Sunol fault, which cuts through Calaveras, Halls, and San Felipe valleys, divides the region into two areas, which are geologically almost distinct. The ridges on the two sheets are principally synclinal, and the valleys anticlinal or fault valleys, with the exception of the Santa Clara, which appears to be a great syncline.

Presented without notes; illustrated by maps, geological sections, and geological columns. Discussion by Clark, Louderback, and Lawson.

IRON-ORE DEPOSIT AT BARTH, NEVADA

BY J. CLAUDE JONES

(*Abstract*)

The Barth deposit of iron ore is a large, irregular mass of hematite inclosed in a basic andesite. The hanging wall contact is usually sharply defined, although some slipping has taken place between the ore and the andesite. In places the contact is quite irregular and the hanging wall pitted as if cor-

roded by the ore-bearing solutions. Many angular fragments of the andesite have been included in the ore near the foot wall and ramifying veins of ore extend out into the andesite. Many of the smaller fragments of andesite have been altered to phlogopite and occasional veins of the latter occur in the ore. Apatite in microscopic crystals is disseminated through the ore body, and near the foot wall is often segregated in nodules and small veins. Limonite, calcite, and quartz of secondary origin are the only other minerals occurring in the ore. The ore body is evidently a metasomatic replacement of the andesite by hematite, magnetite, and apatite introduced by heated solutions intimately connected with igneous activity and presumably closely following the solidification of the andesite.

Presented in abstract from notes. Discussion by Louderback and Rogers.

VENTURA COUNTY OIL FIELDS

BY ROBERT W. MORAN

(*Abstract*)

The paper dealt with the stratigraphy and some structural details of the region. It also touched on the possible origin of the oil.

Presented from notes; illustrated with maps and lantern slides. Discussion by Louderback and Clark.

THE OLDEST FOSSILS

BY ANDREW C. LAWSON

Read from manuscript, and illustrated by maps and specimens. Discussion by Branner and Merriam.

Published in Memoir No. 28 of the Geological Survey of Canada, 1912.

The meeting adjourned at 5.45.

ANNUAL DINNER

Friday evening at 6 o'clock, at Stanford Inn, the section held its annual banquet in conjunction with the Le Conte Club and the Paleontological Society. After the dinner the following paper was presented and discussed:

GENERAL FEATURES OF THE STRUCTURE OF THE BEDROCK COMPLEX OF THE SIERRA NEVADA

BY GEORGE D. LOUDERBACK

(*Abstract*)

The lower western slope of the Sierra Nevada is characterized by remarkable linear extent and comparative regularity of relatively thin belts of strata of the "Bedrock Complex." The bearing of this on the interpretation of the structure was pointed out. Criteria for judging the different types of folding in a practically isoclinal complex were discussed, and the conclusion was arrived at that the major structures of the "Bedrock Complex" are of a comparatively simple nature, much more simple than previously considered. The probable nature of folding was indicated, and methods of testing hypothesis in field proposed.

Presented from notes, and illustrated by maps and diagrams. Discussion by Lawson, J. P. Smith, Merriam, and Clark.

Register of the Stanford University Meeting

FELLOWS

F. M. Anderson
J. C. Branner
N. F. Drake
A. S. Eakle
A. C. Lawson
G. D. Louderback
J. C. Merriam
J. A. Taff

Visitors and other geologists taking part in the meeting were:

C. L. Baker
E. P. Carey
B. Clark
C. B. Cunningham
E. G. Gaylord
G. C. Gester
R. S. Holway
J. C. Jones
B. Martin
R. W. Moran
G. E. Postma
W. G. Reed
A. F. Rogers
D. T. Smith
J. P. Smith
W. Stalder
E. C. Templeton
C. E. Weaver
G. A. Wilcox
H. O. Wood

There were also present a number of students and other visitors.

Altogether the attendance was as follows: Friday morning meeting, 38; Friday afternoon meeting, 43.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 24, PP. 99-132 MARCH 24, 1913

PROCEEDINGS OF THE FOURTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT NEW HAVEN, CONNECTICUT, DECEMBER 30 AND 31, 1912.

R. S. BASSLER, *Secretary*

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Session of Monday, December 30, 1912

President David White called the Society to order at 10 o'clock at the opening session, Monday morning, December 30, 1912, in Lampson Hall of Yale University. Following some introductory remarks the President called for the first matter of business on the program, the report of the Council, which was read by the Secretary.

REPORT OF THE COUNCIL

To the Paleontological Society in Fourth Annual Meeting assembled:

The regular meeting of the Council was held at Washington, D. C., immediately following the adjournment of the Society, on December 30, 1911. Since this meeting all business of the Society has been arranged as heretofore, by correspondence. The details of administration for the Society's fourth year are presented in the following reports of officers:

Secretary's Report

To the Council of the Paleontological Society:

Meetings.—The proceedings of the third annual meeting of the Society, held at Washington, D. C., December 28 to 30, 1911, have been published in volume 23 of the Bulletin of the Geological Society of America, pages 77–92, and distributed to the members of the Society. Other publications, including the symposium on vertebrate paleontology, have also been sent to the members.

Upon the adjournment of the Washington meeting the newly-elected Council held its first meeting and prepared a list of officers for 1913.

The Council's proposed ballot, with the announcement that the fourth annual meeting of the Society would occur at New Haven, Connecticut, at the invitation of the New Haven members, was forwarded to the members on March 15, 1912.

Membership.—During the past year the Society has lost one of its correspondents by death, Prof. E. Koken, of the University of Tübingen. Two resignations have occurred. The twelve candidates elected at the third annual meeting have been added to the membership, and, upon request, two Fellows of the Geological Society of America, G. H. Chadwick and L. W. Stephenson, were placed on our rolls with the approval of the Council. The present enrollment of the Society is 135. Seventeen candidates are before the Society for election and five applications are under consideration by the Council.

At this year's election for Fellows in the Geological Society of America members Charles Butts and Edwin Kirk, of the Paleontological Society, were elected to Fellowship on the nomination of individual Fellows of the two Societies.

Committee on Publication Fund.—At the Washington meeting Dr. Charles D. Walcott and Prof. Charles Schuchert, the latter as chairman, were appointed a committee to secure a publication fund. This committee reports that it has not yet succeeded in raising such a fund or in making any progress toward a publication for the Paleontological Society. The chairman has asked that the committee be retained for another year, to which the Council has agreed.

Publication of Abstracts.—As it has been inexpedient heretofore for various reasons to publish abstracts of papers offered for presentation at the meetings and impossible to print all the papers submitted, the Council voted to print all abstracts in the Proceedings. The Secretary therefore has introduced all the abstracts submitted in the present minutes.

Pacific Coast Section.—The Secretary of the Pacific Coast Section of the Society reports that their third annual meeting was held in the Geology Building at Stanford University, California, on Saturday, April 6, 1912, with President J. P. Smith presiding.

The minutes of this meeting are printed on pages 126 to 132 of this Bulletin.

Respectfully submitted,

R. S. BASSLER,
Secretary.

WASHINGTON, D. C., *December* 26, 1912.

TREASURER'S REPORT

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending December 21, 1912:

RECEIPTS

Cash on hand December 21, 1911		$183.07	
Dues (with arrears) from 55 members		171.00	
			$354.07

EXPENDITURES

Treasurer's office:			
Postage	$3.79		
Expressage	.45		
Supplies	6.35		
		$10.59	
Secretary's office:			
Expenses, 1911	$50.45		
Secretary's allowance for clerical help	50.00		
		100.45	
Geological Society of America:			
125 separates from volume 23, part I	$3.60		
Excess corrections on Symposium	27.00		
Symposium separates	25.65		
		56.25	
Dues returned to one member (Fellow G. S. A.)		3.00	
			170.29
Balance on hand December 21, 1912			183.78
			$354.07
Net increase in funds			.71
Outstanding dues			18.00

Respectfully submitted.

RICHARD S. LULL,
Treasurer.

NEW HAVEN, CONNECTICUT, *December* 26, 1912.

APPOINTMENT OF AUDITING COMMITTEE

Upon motion, W. A. Parks and W. J. Sinclair were appointed as a committee to audit the Treasurer's accounts.

ELECTION OF OFFICERS AND MEMBERS

The declaration of the vote for officers for 1913 and for members was the next matter of business and was announced by the Secretary as follows:

OFFICERS FOR 1913

President:

Charles D. Walcott, Washington, D. C.

First Vice-President:

H. S. Williams, Ithaca, N. Y.

Second Vice-President:

G. R. Wieland, New Haven, Conn.

Third Vice-President:

Bashford Dean, New York City.

Secretary:

R. S. Bassler, Washington, D. C.

Treasurer:

Richard S. Lull, New Haven, Conn.

Editor:

Charles R. Eastman, Pittsburgh, Pa.

MEMBERS

Charles L. Baker, University of California, Berkeley, Cal.
Paul Bartsch, U. S. National Museum, Washington, D. C.
Thomas A. Bostwick, 43 Livingston Street, New Haven, Conn.
John P. Buwalda, North Yakima, Wash.
Bruce L. Clark, University of California, Berkeley, Cal.
Roy E. Dickerson, 1320 Fifth Avenue, San Francisco, Cal.
Norman McDowell Grier, Yale University Museum, New Haven, Conn.
Harold Hannibal, University of Washington Museum, Seattle, Wash.
J. C. Hawver, Auburn, Cal.
Otto E. Jennings, Carnegie Museum, Pittsburgh, Pa.
W. S. W. Kew, San Diego, Cal.
Bruce Martin, University of California, Berkeley, Cal.
G. B. Moody, 2632 College Avenue, Berkeley, Cal.
W. O. Moody, 2632 College Avenue, Berkeley, Cal.
Robert B. Moran, Palo Alto, Cal.
John R. Pemberton, Hydrographic Survey, Argentina.

ANNOUNCEMENT AS TO PRESENTATION OF PAPERS

The Chair then announced that following the request of some of the members, and on account of the length of the program, the more technical papers dealing with vertebrate paleontology would be read in a separate section later in the day and that the remainder of the morning session would be devoted to papers upon general paleontology taken up in the following order:

The following paper was presented by the author from manuscript and illustrated with lantern slides; 30 minutes. Discussed by A. W. Grabau and Charles Schuchert.

ALPHEUS HYATT AND HIS PRINCIPLES OF RESEARCH

BY ROBERT T. JACKSON

(*Abstract*)

Professor Hyatt's personality. Stages in development from the egg to the adult and old age; the most important basis for phylogenetic work. Classification of stages; a convenience in exact description. Acceleration of development; an explanation of how stages come to occur. Senescence, a period in life history much overlooked; of prophetic significance. Colonial stages and localized stages in development; the natural outcome of Hyatt's work as advanced by his followers. Parallelism; the taking on of similar structural forms on independent lines; an aid and a danger to the phylogenist. Larval adaptation; special features built up as youthful adaptations and not of phylogenetic significance.

The next paper was presented without manuscript and illustrated with lantern slides; 30 minutes.

RESTORATION OF TERTIARY MAMMALS

BY WILLIAM B. SCOTT

(*Abstract*)

A drawing of a fossil animal restored in the flesh is not an entirely imaginary thing. The bones of the skeleton show clearly the points of origin and insertion of the muscles which define the body contours, and by the size, shape, degree of roughness, etcetera, of these points of attachment, a fairly good idea of the size of the muscles producing them may be gained. Consequently, by sketching the outlines of these muscles on a drawing of the skeleton, giving them contours proportionate to the parts they have to move, a fairly accurate idea of the body outlines of the fossil animal may be obtained.

The presence, absence, length, and color of the hair on tail and body, the color pattern, the shape of the ears and of the lips and nose are characters which cannot be deduced from the skeleton and are largely conjectural in our restorations of fossil mammals. As the young of many mammals are striped or spotted, becoming solidly colored later in life, we may, perhaps, infer that the earlier forms in these groups, geologically speaking, were, on the principle of recapitulation, striped or spotted.

The next paper was read by the author from manuscript and illustrated with photographs; 20 minutes.

PALEOZOIC ARACHNIDA—SCORPIONS AND SPIDERS

BY ALEXANDER PETRUNKEVITCH[1]

(*Abstract*)

One hundred and one specimens of Paleozoic Arachnida, mainly from Mazon Creek, Ill., were studied and found to belong to forty-two species distributed over twenty-five genera, of which twenty-four species and eleven genera are new to science. A representative of the order Solifugæ, heretofore not known from the Paleozoic, has been found in *Protosolpuga carbonaria*. A new order, Kustarachnæ, had to be established for the three species of the genus Kustarachne. All forms studied show the high development which the Arachnida had attained already at that period and suggest the probability of polyphyletic origin. A comparison with the European Carboniferous fauna shows that the American forms, while closely related, are distinct from the European species. Moreover, they are more related to the recent tropical fauna than to the fauna of the moderate zone.

Before the adjournment of the morning session, which occurred at 12.30 p. m., Professor Schuchert announced the gift to the Society by members John M. Clarke and Rudolph Ruedemann of their monograph on the Eurypterida in two volumes, which had just come from the press. The volumes were exhibited and placed for more detailed examination in the adjoining exhibition-room.

PRESIDENTIAL ADDRESS

At 2 p. m. the members met for the afternoon session, with the address of the retiring President, Prof. William B. Scott, first on the program. Professor Scott chose for his subject

THE PERMANENCY OF THE CONTINENTS AND OCEANS

Following the presidential address a paper by Professor Loomis, transferred from the program of the Geological Society of America, was presented by the author without manuscript and illustrated by charts; 20 minutes. Discussed by W. B. Scott and W. J. Sinclair.

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[1] Introduced by Charles Schuchert.

PRELIMINARY DISCUSSION OF THE STRATIGRAPHY AND AGE OF THE PYROTHERIUM BEDS OF PATAGONIA

BY FREDERICK B. LOOMIS

(*Abstract*)

First description of the lay of the beds above and below—characteristics of fauna—conclusions as to age.

ORGANIZATION OF SECTION ON VERTEBRATE PALEONTOLOGY

The members of the Society especially interested in vertebrate paleontology now organized a section for the reading of their more technical papers, meeting apart from the main section, which continued with the papers on general paleontology and stratigraphy. The minutes of the vertebrate section are given on pages 117 to 121.

The following paper was presented without notes and illustrated by lantern slides and diagrams; 20 minutes. Discussed by A. W. Grabau, R. S. Bassler, E. O. Ulrich, W. A. Parks, A. F. Foerste, G. H. Chadwick, and M. Y. Williams.

THE CATARACT: A NEW FORMATION AT THE BASE OF THE SILURIC IN ONTARIO AND NEW YORK

BY CHARLES SCHUCHERT

(*Abstract*)

It was shown that the Medina formation of western New York is not at the base of the Siluric, but that fully 50 feet of the Medina at Niagara Falls belong to a new formation, named the Cataract from Cataract, Ontario, where it is well developed (82 feet thick) and replete with fossils. The Cataract formation was traced from Niagara Falls, New York, to the Manitoulin Islands, where it is 110 feet thick, the lower portion (45 feet) consisting of thin-bedded magnesian limestone, and the upper of red shales barren of fossils.

On account of the similarity of subjects, Mr. Ulrich's paper on the Medina problem, transferred from the Geological Society of America, was voted next on the program. It was read from manuscript and illustrated with charts; 30 minutes. Discussed by A. W. Grabau, G. H. Chadwick, and A. F. Foerste, with reply by the author.

THE MEDINA PROBLEM

BY E. O. ULRICH

(*Abstract*)

A brief history of the Medina sandstone was first presented, special emphasis being placed on the definition given by Vanuxem, who referred the Oneida to

the base of the Clinton, hence above the true Medina, an arrangement which the present author indorses. Typical sections in New York and following these the sections corresponding in general with the Medina in the Appalachian Valley from central Pennsylvania to east Tennessee, in central Alabama, Ohio, Indiana, and southern Illinois, were briefly discussed and the beds correlated. The evidence presented by the author was believed to establish that the Clinch sandstone of Tennessee is the equivalent of the Tuscarora in Pennsylvania and in general also the equivalent of the upper part of the Medina, beginning with the Whirlpool sandstone in New York. It was shown further that the horizon of the *Arthrophycus harlani* is at the top in each case of the mentioned formations. It was recommended that the term Clinch be adopted in place of Tuscarora throughout the Appalachian Valley for the Upper Medina, and that the term Juniata should be adopted in New York as well as in Pennsylvania and perhaps elsewhere in the Appalachian Valley for the Lower Medina, displacing the Queenstown. The correlation of the Upper Medina is based on an aggregate of over 75 species of fossils, a very large portion of which are new. It was further recommended that the term Medina be retained in its original significance, thus making it today a series term, equivalent in rank to the Niagaran and divided like it into two groups. Inasmuch as the Lower Medina is equivalent to the greater part, if not the whole, of the Richmond, the latter name becomes the time term for the lower group and possibly Anticosti for the upper. Finally it was shown by fossil and stratigraphic evidence that the typical Rockwood formation of southeastern Tennessee includes representatives of the Juniata and of all of the distinguishable members of the Upper Medina in New York, but that it does not include beds of Clinton age. The typical Rockwood thus corresponds to the whole of the Medina and is distinctly older than the Clinton, with which it had been hitherto correlated.

At 5.15 the Society adjourned for the day. In the evening the members took part in the annual dinner with the Fellows of the Geological Society of America.

SESSION OF TUESDAY, DECEMBER 31

Tuesday morning the Society was called to order by the President at 9.30 o'clock and the Auditing Committee was called upon to report as the first matter of business. This committee stated that the accounts of the Treasurer were found to be correct; whereupon it was voted that their report be accepted. Vice-President Ruedemann then took the chair and announced that the rest of the session would be devoted to the completion of the papers on general and invertebrate paleontology and stratigraphy and paleobotany.

The following paper was then presented by the author without notes and illustrated by drawings; 30 minutes. Discussed by R. S. Bassler, with reply by the author and by R. S. Lull, T. C. Brown, and R. T. Jackson:

PALEONTOLOGICAL NOTES: 1. POLYPHYLETIC GENERA. 2. AN ILLUSTRATION OF WAAGEN'S THEORY OF MUTATIONS

BY A. W. GRABAU

(*Abstract*)

1. *Polyphyletic genera.*—The genus Philipsastræa among the Paleozoic corals is a complex of at least three genetic series of which its species represent the end members. The first is the typical group, derived, as Frech has shown, from Acervularian (Prismatophyllum) ancestors. This group is essentially European, having emigrated, however, into western North America. The second group appears to be a derivation from Strombodes, and includes the typical Onondaga species of eastern North America, such as *P. gigas* Billings, etcetera. A third group is apparently derived from the compound Heliophyllums, and is represented by *P. billingsi* of Iowa and Michigan. Other illustrations will be given from Heliophyllum, etcetera.

2. *An illustration of Waagen's theory of mutation.*—Among the forms classed together under the Linnæan species *Spirifer mucronatus* are at least five distinct mutations, occurring with constant diameters in various horizons of the Middle Devonic of North America. Each of these would be considered a separate specific group if occurring alone. In each group there is further an orthogenetic series showing progressive modifications in definite directions within the same geologic horizon. These would constitute the variations of Waagen, but are better considered as submutations, since they also represent definite modifications.

The vertebrate section of the Society, having completed its program, now met with the general section. The paper on Cuban Fossil Mammals, by W. D. Matthew, before the vertebrate section, proved of such general interest that upon motion of the Secretary it was repeated at this point.

CUBAN FOSSIL MAMMALS; PRELIMINARY NOTE

BY W. D. MATTHEW

Presented without notes and illustrated by drawings and specimens; 10 minutes. Discussed by Charles Schuchert, G. F. Eaton, R. S. Lull, and W. D. Matthew. An abstract of this paper is presented on page 118.

The following paper was then read for the author by A. F. Foerste and illustrated by charts; 30 minutes. Discussed by R. S. Bassler:

NOMENCLATURE, STRUCTURE, AND CLASSIFICATION OF THE CREMACRINIDÆ

BY E. O. ULRICH

(*Abstract*)

The paper aims primarily to clear up the tremendously involved synonymy of a group of crinoids hitherto commonly known as the Calceocrinidæ, it being shown that the term Calceocrinus was never properly established. As it has always been misinterpreted and is liable to continue to be misinterpreted, the name is dropped finally and the term Cremacrinidæ, proposed by Ulrich in 1886, is used in its stead. A review of the evidence led to an investigation of this group of crinoids as a whole, with the result that a reclassification was found to be necessary. Of the seven or eight genera previously suggested or recognized, all but three were discarded on the ground of preoccupation or actual synonyms. Under the searching and comprehensive treatment, however, it became necessary to institute six previously undescribed genera. These studies, which included the type specimens of all the species available, were based in large part upon the extraordinarily complete representatives of the family in the Frank Springer collection.

The next paper was presented without notes and illustrated by lantern slides; 20 minutes. Discussed by P. E. Raymond.

RICHMOND FORMATIONS OF THE PROVINCES OF ONTARIO AND QUEBEC IN CANADA

BY A. F. FOERSTE

(Abstract)

Richmond formations are widely extended throughout Ontario and Quebec, but belong chiefly to two horizons comparable with the Waynesville and Saluda of Cincinnatian areas. The Queenstown shales are of Ordovician age. South of Georgian Bay they contain a Saluda fauna. Farther westward, on Manitoulin Island, the Queenstown shales are represented by much more fossiliferous, blue and light brown limestones and clays. Paleozoic seas probably traversed the areas now mapped as Huronian and Archean. There are traces of the Richmond fauna of Anticosti on Snake Island, in Lake St. John, and at various localities between Ottawa and Three Rivers, but these traces are not sufficient to suggest any free connection with the Anticosti area. The Saluda may have been part of a circumpolar fauna. The Waynesville appears to have entered Ontario and Quebec chiefly from the Cincinnatian areas of Ohio and Indiana.

In the absence of the author the next paper was read by R. S. Bassler and illustrated by photographs; 20 minutes.

CRINOID GENUS SCYPHOCRINUS AND ITS BULBOUS ROOT CAMAROCRINUS

BY FRANK SPRINGER

(Abstract)

This paper is based chiefly upon a remarkable collection of specimens which the author considers to be specifically identical with *Scyphocrinus elegans* of Zenker from Bohemia. The material was obtained during the past season in Helderbergian strata, near Cape Girardeau, Missouri, and consists of numerous finely preserved crowns of great size—some 18 inches in length—intermingled with a mass of long stems, and many of the chambered bulbs heretofore described as *Camarocrinus* all formed part of a large colony.

The evidence is held to prove beyond doubt not only that *Camarocrinus* is the bulbous distal end of the stem of *Scyphocrinus*, but that it served as a root for permanent or temporary fixation of the crinoid to the sea bottom, and was not a float, as hitherto supposed by authors generally. The paper will be published in the near future, with ample illustrations.

The last paper of the morning session was presented without manuscript and illustrated by charts; 20 minutes.

CORRELATION OF THE MIDDLE ORDOVICIAN FORMATIONS OF ONTARIO AND QUEBEC

BY P. E. RAYMOND

(*Abstract*)

The Trenton of Ontario, with its large and varied fauna, differs markedly from the Trenton of Quebec, which has a comparatively small fauna, made up largely of cosmopolitan species. Further, the crinoid and cystid faunas of the west contrast strangely with the Cryptolithus fauna of the east. A study of the principal exposures of the Trenton from Collingwood, on Lake Huron, to Picton, on Lake Ontario, and Rockland, on the Ottawa River, shows that in Ontario the Trenton can be divided on the basis of fossils into four principal zones, one of which is younger than the strata at Trenton Falls, New York. A study of the strata in the vicinity of Montreal and Quebec shows that the sections there contain three faunal zones, two of which are older than the strata at the typical locality. A comparison is also made with the sections in Minnesota and Kentucky.

The stratigraphic relations of the sub-Trenton strata in Ontario are next discussed, in an attempt to show that the Pamelia, Lowville, and Black rivers are parts of one group of post-Chazy age.

At 12.15 the Society adjourned for luncheon, meeting again at 2 o'clock, with Vice-President Ruedemann presiding. The papers upon general and invertebrate paleontology and stratigraphy were then continued and the following paper was read by title:

THE ALEXANDRIAN SERIES IN MISSOURI AND ILLINOIS—STRATIGRAPHY AND PALEONTOLOGY. PART I

BY T. E. SAVAGE

(*Abstract*)

The Alexandrian series comprises a number of early Silurian formations that outcrop at intervals along both sides of the Mississippi River between Cairo, Illinois, and Hannibal, Missouri, and appear also in Will and Kankakee counties, in northeast Illinois. They occupy a position between the Richmond below and the top of the Brassfield limestone, and are separated from the underlying and overlying rocks by a sedimentary hiatus. The sequence of the several formations from below upward is: Girardeau limestone, Edgewood limestone, Essex limestone, and Sexton Creek (Brassfield) limestone. The

Bowling Green limestone. Noix oolite and Channahan limestone are considered members of the Edgewood limestone, representing local facies of this formation. The several formations are unconformable among themselves, but their faunas are closely allied. They are thought to have been deposited in an oscillating sea that advanced successively from the south, the sediments of each succeeding advance overlapping those of the preceding. The basin in which they were deposited was a rather narrow extension of the Gulf of Mexico embayment toward the north and northeast. During Edgewood time this depression was deepest near the west side, having a longer and more gentle slope toward the east. The name Thebes Basin is proposed for this general area of sedimentation during Alexandrian time.

The faunas of the Girardeau and Edgewood limestone are figured and described.

The next paper was read from manuscript: 10 minutes. Discussed by Rudolph Ruedemann, Eliott Blackwelder, E. S. Moore, Chester A. Reeds, Gilbert Van Ingen, and G. R. Wieland.

NOTES ON THE ORIGIN OF CERTAIN UPPER CAMBRIAN AND LOWER ORDOVICIAN SEDIMENTS OF CENTER COUNTY, PENNSYLVANIA

BY THOMAS C. BROWN[2]

(Abstract)

In the central part of Center County, north and west of State College, Pennsylvania, are exposed a series of Paleozoic sediments of Upper Cambrian and Lower Ordovician age. They consist of two series of limestones separated by a few hundred feet of sandstone. The limestones are in part oolitic and in part composed of pebble-like structures, to which the name "Edgewise conglomerate" has been applied. Chert bands are numerous, and many of the oolitic layers have been almost completely replaced by silica. The sandstone consists of extremely well rounded sand grains, which indicate a peculiar origin.

In certain of the limestone layers are peculiar disklike structures which in their section show a banded or concentric structure and which were probably produced by calcareous algæ. Their position in certain beds proves that they could not have been produced as clastic structures. The structures of the sandstone and the nature of the component grains indicate a wind-blown origin.

The following paper was read by title:

SPIRIFEROIDS OF THE LAKE MINNEWAUKA SECTION, ALBERTA

BY H. W. SHIMER

(Abstract)

Fossils are extremely abundant in this area. Brachiopods are especially conspicuous, and of these the spiriferoids exceed all others in number of indi-

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[2] Introduced by R. S. Bassler.

viduals and in vertical range, extending from the Intermediate limestone of the Devonian, through the great thicknesses of the Banff limestones and shales, to the Rocky Mountain quartzite of the Pennsylvanian. A brief discussion of these species will be given, with some notes on their evolution from lower to higher beds.

The next paper was read from manuscript and illustrated with charts; 20 minutes. Discussed by R. S. Bassler.

CONTRIBUTIONS TO THE BLACK SHALE PROBLEM

BY CHARLES BUTTS

(*Abstract*)

The Chattanooga (black) shale is 20 to 40 feet thick at Chattanooga. It thins southward, and at Birmingham, Alabama, is only 2 or 3 feet thick. Northward the black shale thickens to 500 feet at Cumberland Gap and apparently 1,500 feet at Big Stone Gap, Virginia. Thirty miles northeast of Big Stone Gap, at Dump Creek, Virginia, is an upper black shale 25 feet thick and a lower 200 to 300 feet, with bottom not exposed, and between the two is 1,500 feet of green shale and thin sandstone, which is clearly Chemung and Portage. On the west escarpment of Pine Mountain, in eastern Kentucky, the black shale is 800 feet thick and bottom not exposed, with no Chemung and Portage.

The black shale has always been regarded as Devonian until that identification was challenged in recent years by E. O. Ulrich. In this paper it is shown that the lower shale of the Dump Creek section and the lower part of the black shale mass at Big Stone Gap and at least the lower 300 feet at Cumberland Gap is Devonian and probably represents the Genesee shale, while the upper black shale in the Dump Creek section may be Mississippian, and that this bed may be represented by the upper 200 to 300 feet of the black shale at Big Stone Gap, etcetera, the Chemung and Portage separating the two black shales at Dump Creek having thinned out. South of Cumberland Gap the Devonian part of the black shale may lap out and only the upper, possibly Mississippian, part persist as the Chattanooga shale.

The next paper was presented from notes by the author; 15 minutes.

NOTES ON THE EOCENE OF THE BIG HORN BASIN OF WYOMING

BY W. K. GRANGER

The two following papers were read by title:

NEBRASKA EURYPTERIDS

BY E. H. BARBOUR

PLANT TISSUE IN THE CARBONIFEROUS SHALES OF NEBRASKA

BY E. H. BARBOUR

PAPERS ON PALEOBOTANY

The papers upon paleobotany were then taken up, with Vice-President Ruedemann still presiding.

On account of the little time still remaining it was necessary to read most of these papers by title.

PALEOBOTANICAL STUDY OF THE COAL-BEARING ROCKS OF THE RATON MESA REGION OF COLORADO AND NEW MEXICO

BY F. H. KNOWLTON

(*Abstract*)

For almost a quarter of a century the coal-bearing rocks of the Raton Mesa region of Colorado and New Mexico have been referred to a single geological formation—the Laramie—largely because of their stratigraphic position and on the mistaken assumption that they were similar in all respects to the Laramie of the Denver Basin of Colorado. However, since it has been demonstrated by Lee that there is a widespread unconformity in the midst of this Raton Mesa section, it became necessary to interrogate anew other lines of evidence, this being the *raison d'etre* for the present paleobotanical investigation. This study, which is based on the most extensive collections of fossil plants thus far brought together from any of the Rocky Mountain areas, shows conclusively that the beds below the unconformity are distinctly Cretaceous in aspect, and find their closest affinity with the upper portion of the Montana group, while the beds above the unconformity are distinctly post-Laramie in age and closely related to the Denver formation of the Denver Basin, and to the Wilcox formation of Louisiana and Mississippi. The Wilcox formation, being above marine Eocene, fixes the age of the Raton formation as Eocene. No Laramie is at present known from the Raton Mesa region.

STATUS OF THE STUDY OF THE FOSSIL FLORAS OF THE ATLANTIC COASTAL PLAIN

BY EDWARD W. BERRY

(*Abstract*)

A brief account of the floras of the Atlantic Coastal plain and the progress that has been made in their description.

ROOTS IN THE UNDERCLAYS OF COALS

BY DAVID WHITE

(*Abstract*)

On close inspection the floor, usually an "under clay" beneath the coal beds in the American coal fields, is, in the great majority of cases, found to contain roots of vascular plants in their place of growth. The prevalent occurrence of such roots of various kinds, which are to be seen under the commercially workable coals in all fields examined, whether of Tertiary, Mesozoic, or Car-

boniferous age, clearly indicates that in most areas, at least, the coal swamps were not too deeply submerged or inundated to permit vascular plants to root and grow in place at the commencement of the formation of the mother peat. In some cases evidence points also to the growth of arborescent vegetation on the surface of the growing peat. Such growth unquestionably occurred on the partings of certain coals and was not infrequent in the roofs of the submerged peats.

The following paper was presented without notes by the author and illustrated by lantern slides; 10 minutes. Discussed by A. W. Grabau.

CORALLINE ALGÆ IN AN ORDOVICIAN DOLOMITE

BY ELIOT BLACKWELDER

(*Abstract*)

The Bighorn and Jefferson dolomites of western Wyoming consist very largely of tangled upright growths, the exact nature of which is unsettled. A study of the individual stalks, their mutual relations, and their internal structure brings out some suggestive resemblances between these problematic fossils and certain modern coralline algæ.

The remaining papers, with one exception, were read by title:

ORIGIN OF THE LIASSIC FLORA OF THE MIXTECA ALTA

BY G. R. WIELAND

WOOD STRUCTURE OF THE CYCADEOIDEÆ (WITH DEMONSTRATION)

BY G. R. WIELAND

FLORAL FEATURES OF THE CYCADEOIDEÆ (WITH DEMONSTRATIONS)

BY G. R. WIELAND

EXHIBITION OF POLISHED SPECIMENS OF OZARKIAN STROMATOPOROIDS FROM PENNSYLVANIA

BY G. R. WIELAND

Presented without notes and illustrated by specimens and sketches; 5 minutes.

NOTE ON A PROCESS OF FOSSILIZATION IN THE PALEOZOIC LYCOPODS

BY E. M. KINDLE

(*Abstract*)

Striking examples of a type of fossilization in which the bark is preserved in exquisite detail, while the space within the bark is wholly filled with fine siliceous sediments, showing no trace of the original plant structure, occur

frequently among the various species of Sigillaria and Lepidodendron. The author here calls attention to the remarkable resistance to decay of the bark of the common birch and the equally striking susceptibility to decay of the wood of this tree. Consideration of the differential rate of decay of the bark to the wood of the birch throws much light on the process which has so often produced the kind of fossilization represented by the sand-filled bark of Lepidodendron. It appears most probable that the dark cylinder of the Carboniferous lycopods were generally hollowed out by rapid decay of the wood and then filled with sediment before fossilization began, just as the empty birch bark of the trunks are now being prepared for fossilization in Canadian lakes and rivers.

PRELIMINARY CORRELATION OF THE CRETACEOUS AND TERTIARY FLORAS OF ALASKA

BY ARTHUR HOLLICK

(Abstract)

Previous to the year 1902 little or nothing was known in regard to the Cretaceous flora of Alaska. During that year A. J. Collier, of the U. S. Geological Survey, made collections of fossil plants at several localities in the lower part of the Yukon River Valley, and in the following year further collections in the same region were made by the writer. The plants included in certain of these collections proved to be Cretaceous in age, and subsequent collections by other field parties of the Survey elsewhere in the territory indicated the presence of a Cretaceous flora at a number of other localities.

The Tertiary flora, first mentioned briefly by Grewingk in 1850, was subsequently found at many localities in the southern part of the territory and was described by Goeppert in 1861, Heer in 1868 and 1869, Eichwald in 1871, Lesquereux in 1883, Newberry in 1883 and 1898, and Knowlton in 1904. The writer also discussed it briefly in 1911.

Little or no attempt was made, however, to correlate the Tertiary floras of the different localities, and all were generally classed as "Arctic Miocene" in age—now recognized as Eocene.

In 1892 Dall and Harris proposed the name "Kenai" as a group name for certain Tertiary strata exposed at Katchemak Bay, Kenai Peninsula, and that name has since then been more or less loosely applied to a number of different beds in which Tertiary plants were identified.

A critical examination by the writer during the past two years of collections from about one hundred and fifty localities has resulted in the differentiation of the typical Kenai flora, which is Upper Eocene in age; a Lower Eocene flora which is well exemplified in collections from the Hamilton Bay region of Kupreanof Island, and at least two of Cretaceous age, represented in collections from localities in the lower Yukon Valley and the Alaskan Peninsula.

The scope of this paper includes a preliminary correlation of the floras, characteristic species of each, localities, and bibliography.

At 4.15 the Society adjourned.

MINUTES OF SECTIONAL MEETING ON VERTEBRATE PALEONTOLOGY

The section organized Monday afternoon, December 30, at 3.15, with R. S. Lull as Chairman. W. D. Matthew was elected Secretary, and the section proceeded to the reading of papers.

The first paper presented was illustrated with lantern slides; 30 minutes. Discussed by W. D. Matthew.

THE YALE EXPEDITION OF 1912

BY R. S. LULL

(*Abstract*)

The speaker reviewed briefly the itinerary and results of the expedition which he had conducted during the summer of 1912, in the Panhandle region of Texas, for the purpose of securing complete skeletons of fossil horses to supplement the Marsh collection showing the evolution of the horse. The most important specimens secured were practically complete skeletons of the fossil horse *Equus scotti* and ground sloth *Mylodon* from the Rock Creek formation, and a large series of less complete specimens from the Pleistocene and later Tertiary formations.

The following paper was then presented by the author; 20 minutes. Discussed by W. D. Matthew.

RELATIONS OF THE TUPAIIDÆ AND OF EOCENE LEMURS, ESPECIALLY NOTHARCTUS

BY W. K. GREGORY

(*Abstract*)

Recent studies upon the *Tupaiidæ*, or tree-shrews, have shown that this group of Insectivora is allied to the Lemurs and in most respects is morphologically ancestral to them. The Eocene genus *Entomolestes* is referable to this family, and other early Eocene genera *Apatemyidæ*, *Mixodectidæ*, etcetera, appear to be more or less intermediate between Insectivores and Lemuroid Primates. The genera *Notharctus* and *Pelycodus* of the Middle and Lower Eocene are true Lemuroidea, very close in the detailed construction of vertebræ, limb bones, and feet to the modern genus *Lemur*, but considerably more primitive in skull, lacking the peculiar specialization which distinguish the modern Lemuridæ. While *Notharctus* is somewhat aberrant in molar dentition, *Pelycodus* may be regarded as ancestral to modern lemurs. The higher primates are more probably derivable from some of the Anaptomorphid genera.

There was then presented

CERTAIN THEORETICAL CONSIDERATIONS AFFECTING PHYLOGENY AND CORRELATION

BY W. D. MATTHEW

(*Abstract*)

The author emphasized the importance of the hybridism and admixture of blood resulting from successive or continuous migration movements and pointed out the resultant complexity of the phylum in any race of animals and the effects upon its composition and progressiveness, of more or less remoteness from the center of dispersal.

The next paper, illustrated by lantern slides (10 minutes) and discussed by E. C. Case and W. D. Matthew, was entitled

HOMOLOGY OF THE "ALISPHENOID" AND "LACHRYMAL" IN RECENT AND FOSSIL VERTEBRATES

BY W. K. GREGORY

(*Abstract*)

The author reviewed the recent studies of Gaupp upon the homologies of these bones in mammals and reptiles, but dissented from his conclusions, which were based chiefly upon comparisons of the modern lizard skull with that of mammals. The lizards are highly specialized and remote from mammalian affinities; the Permian Therocephalia and Cynodonts, approaching nearly the ancestry of mammals, afford a much better guide to the homologies of the skull bones. The recent studies of Broom, and especially of Watson, on the skull structure in Cynodonts afford data for homologizing the bones of the skull with those of mammals. Whatever homologies were accepted, the author protested against hasty and unnecessary changes in nomenclature of the skull bones in different vertebrate groups. Homologous bones in different classes of vertebrates may be totally different in function and relations, and it is neither necessary nor desirable that the nomenclature of such bones should be identical.

The next paper, illustrated by charts and specimens (10 minutes), was

CUBAN FOSSIL MAMMALS; PRELIMINARY NOTE

BY W. D. MATTHEW

(*Abstract*)

The extinct land vertebrate fauna of Cuba had been practically unknown until the recent discoveries of Dr. Carlos de la Torre, of Havana, and Mr. Barnum Brown, of the American Museum of Natural History. These collections, in addition to specimens secured by Senor Moreno, of Havana, are now at the American Museum in course of preparation and study. A preliminary review showed that the fauna consisted of a remarkable group of ground sloths, a few rodents allied to the Hutias still living on the island; a gigantic crocodile, a large land tortoise, and aquatic turtles, lizards, and snakes. Three genera and six species of ground sloths are readily distinguished; all are allied to Megalonyx, but share a number of peculiar and aberrant features which indicate descent from a common ancestor nearly allied to the Miocene ground sloths of South America. The entire fauna, so far as studied, indicates South American derivation; it is wholly unlike the contemporary and earlier faunæ of Florida, which are typically North American. It indicates that Cuba has not been connected with North America during the Tertiary, and any connection with South or Central America must have been about the Miocene epoch, the fauna indicating isolation since that time. The author believed, however, that the Cuban fauna could not be accounted for by any land connections with either continent, but was derivable from occasional immigrants transported on "natural rafts" from South or Central America.

The following papers were read by title:

DEVONIAN FISHES OF MISSOURI

BY E. B. BRANSON

(*Abstract*)

Several species of arthrodires—one chimæroid and two sharks—have been collected by Mr. Rowley from the Devonian shales, near Louisiana, in northeastern Missouri. A discussion of the value of these fossils in correlating the Devonian of Missouri with that of other regions, a description of the species, and a summary of what is known of the Devonian of Missouri make up the contents of this paper.

BRAIN STRUCTURES OF FOSSIL FISHES FROM THE CANEY SHALES

BY C. R. EASTMAN

(*Abstract*)

In April, 1907, some remarkable specimens of Palæoniscid fishes were collected by the writer, in company with Mr. Moritz Fischer, of Cincinnati, in phosphatic nodules occurring at the base of the Waverly and immediately overlying the so-called Genesee black shale, in Boyle County, Kentucky. A number of fish crania belonging to the species, since described as *Rhadinichthys deani* (Iowa Geol. Surv. Rept., 1908, vol. 18), were found preserved in such manner as to display the actual soft parts of the brain cavity, including the semicircular canals in their entirety, the olfactory and optic lobes, cerebral hemispheres, and course of the arteries and various nerves.

Until quite recently this interesting occurrence has remained unique. An analogous instance is presented, however, by the discovery of similar fish-bearing concretions from the Caney shale of Oklahoma in which the conformation of the internal soft parts is clearly visible within the fractured crania. Only a few small-sized specimens have thus far come under the writer's examination, and these are to be made the subject of further study, together with a few associated fish remains, such as sharks' teeth belonging to the genus *Phœbodus*, detached ganoid scales, and the like.

The material in question was collected by Dr. George H. Girty, of the U. S. Geological Survey, and by him placed in the writer's hands for investigation.

As at present known, the invertebrate fauna of the Caney shale consists of about 50 species and varieties, besides a considerable number of indeterminata, and the relationships of this fauna are held by Dr. Girty to warrant a correlation with recognized faunas of Upper Mississippian age. The character of the fish remains tends to support this conclusion, as far as the evidence goes, though it is admittedly slight, and is in conflict with that furnished by the plant remains, which latter favor a correlation with the Pottsville. The question of the age of the Caney shale is discussed by Dr. Girty in Bulletins 377 and 439 of the U. S. Geological Survey, to which reference should be made for full details.

MUTATIONS OF WAAGEN AND OF DE VRIES

BY H. F. OSBORN

COMPARISON OF THE LATE PLEISTOCENE FAUNA OF EUROPE AND NORTH AMERICA

BY H. F. OSBORN

SIGNIFICANCE OF INDICES AND RATIOS IN THE PHYLOGENETIC AND SYSTEMATIC STUDY OF MAMMALS

BY H. F. OSBORN

NEW PLESIOSAURIAN GENUS FROM THE NIOBRARA CRETACEOUS OF NEBRASKA

BY S. W. WILLISTON AND ROY L. MOODIE

(*Abstract*)

The new genus is a member of the widely distributed family, the Elasmosauridæ, and is based on a complete series of cervical vertebræ with limbs and girdle elements. The distinguishing characters of the new genus are the short, uniform centra of the cervical vertebræ from Cloud County, Kansas. The characters of the limbs show the animal to have been a young but nearly mature individual. There are no evidences for the formation of the articular surfaces of the ends of the propodials for articulation with the mesopodial elements. The cervical centra have on the ventral surface throughout a pair of vascular foramina, and the surfaces of all the skeletal elements show evidences of the presence of a richly vascular periosteum. There are 51 cervical vertebræ, preserved with a total length of nearly two meters. The individual vertebræ increase in length and breadth according to the following measurements:

3d	cervical	vertebræ	20	mm.	long,	30	mm.	wide
6th	“	“	23	“	“	32	“	“
12th	“	“	30	“	“	38	“	“
20th	“	“	34	“	“	44	“	“
30th	“	“	41	“	“	52	“	“
40th	“	“	45	“	“	67	“	“
45th	“	“	45	“	“	67	“	“
51st	“	“	46	“	“	72	“	“

The new generic and specific terms *Ogmodirus martini* are proposed for the new animal.

The limbs are short and heavy, with the ends of the propodials not modified for the reception of the mesopodial elements. The anterior and posterior propodials both exhibit traces of the peculiar vascular canals and cavities so often described for the plesiosaurs. In the opinion of the junior author this condition is a persistence of an embryonic condition confined to the plesiosaurs and indicating a distinct evolution in that group. The developing long bones of all vertebrates show precisely the same condition as is exhibited by the adult propodials. The fact that they seem to be more exaggerated in some embryonic plesiosaurian propodials would go to show that the character has been deeply impressed on the organization of some of the group. Other members of the Plesiosauria show this character very little, or not at all. Until the plesiosaurs are better known, no definite solution of the problem can be attained; but it is suggested that the more generalized and plastic forms of the group will be found to exhibit this character, while the development of this character has been obliterated in other forms.

Register of the New Haven Meeting, 1912

Robert Anderson
Harvey Bassler
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Charles Butts
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Samuel Calvin, died April 17, 1911.
Robert H. Gordon, died May 10, 1910.
Dr. E. Koken, University of Tübingen, Tübingen, Germany; died Nov. 24, 1912.

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Minutes of the Pacific Coast Section of the Paleontological Society

Roy E. Dickerson, *Secretary*

The third annual meeting of the Pacific Coast Section of the Paleontological Society was held in the Geology Building, Stanford University, California, on Saturday, April 6, 1912. President J. P. Smith presided.

The following officers were elected for the ensuing year:

President, Frank M. Anderson, Berkeley, California.

Vice-President, Loye Holmes Miller, State Normal School, Los Angeles, California.

Secretary and Treasurer, Roy E. Dickerson, Mission High School, San Francisco, California.

It was voted to hold the next annual meeting at the call of the President, during the week of the spring recess of Stanford University, at the University of California, Berkeley, California.

Following are the abstracts of papers presented:

EOCENE OF SAN PEDRO POINT, SAN MATEO COUNTY, CALIFORNIA

BY ROY E. DICKERSON

(*Abstract*)

Certain beds which rest upon Montara granite were described by Prof. A. C. Lawson in his "Sketch of the geology of the San Francisco Peninsula." Mr. Gerson, in 1907, obtained some fossils from the uppermost portion of these strata which indicate their Eocene age, probably of the Martinez stage.

Discussion

Mr. Lawson called attention to the fact that fossils found some years since at this same locality had been determined by Dr. Stanton and mentioned in his (Lawson's) paper in the Fifteenth Annual Report of the U. S. Geological Survey. He also said that there was probably a fault relation between the San Francisco sandstone and the beds carrying the above fauna.

Mr. Merriam indorsed the author's opinion as to the age of this fauna and expressed the opinion that it was more nearly related to the Lower than to the Upper Martinez.

STRATIGRAPHIC AND FAUNAL RELATIONS OF THE MARTINEZ AND TEJON SOUTH OF MOUNT DIABLO, CALIFORNIA

BY ROY E. DICKERSON

(*Abstract*)

An unconformity exists between the Tejon and Martinez south of Mount Diablo. The unconformity is marked by Pholas (?) borings recognized in two localities three miles apart and an angular unconformity found in two places.

DISCUSSION

Mr. Louderback emphasized the remarkable differences between the Tertiary sediments of the north and south sides of Mount Diablo, apparently indicating complex relationships between land and water and in the diastrophism. He also stated that three or four horizons of Chico fossils had been found south of Curry Canyon.

Mr. Anderson told of a line of division in the Eocene along the east front of the Diablo range from Coalinga north to New Idria. There is probably an angular unconformity with a thin basal conglomerate in the upper division. Coal is present in the Martinez of this region. On the basis of the fossils, Doctor Dall thought that the lower beds were probably Tejon.

EOCENE OF THE COALINGA-CANTUA DISTRICT, FRESNO COUNTY, CALIFORNIA

BY J. A. TAFF

(*Abstract*)

Areal surveys through the Coalinga-Cantua District show that a dual formation of white to pink organic shale, conformably related above to a white to buff sand and conglomerate, is of Eocene age. It has been described as Tejon. This Tejon is overlain in marked unconformity by Lower Miocene sands, and is underlain with equally distinguished disconformity by a group of two or three formations of Eocene age that have been provisionally correlated with the Martinez formation of the Mount Diablo District.

This lower group consists of an upper non-fossiliferous brown shale, a middle fossiliferous brown sandstone, glauconitic and shaly at base, and a lower chocolate shale that has yielded no fossils. The contact at the top of this group shows indications of local pre-Tejon erosion and weathering.

Both groups of Eocene here represented thin out by progressive overlap southward.

The stratigraphic relations of the Martinez with the underlying Cretaceous has not been distinguished.

DISCUSSION

Mr. Anderson said that Aturia had been found in an 8-inch bed of sandstone in the brown chocolate shale, or lowest member of Mr. Taff's section. If the lower group is Martinez, the Coalinga-Cantua area is the most important area of Martinez in California.

Mr. Lawson suggested that the organic shales referred to the Tejon by Mr. Taff may possibly be of Lower Miocene age, and the conditions of sedimentation comparable to the alternating conditions of sandstone and organic shale deposition in the Contra Costa Miocene. Since organic shale had not been found elsewhere in the Tejon, he hesitated to accept the reference of the organic shale portion of the Coalinga-Cantua section to the Eocene.

Mr. Stalder made mention of an unconformity at the same horizon as the one described by Mr. Taff but a few miles north of the limits of Mr. Taff's area. The unconformity here was shown by borings and by considerable discordance in dips.

SUGGESTED PALEONTOLOGIC CORRELATION BETWEEN CONTINENTAL MIOCENE DEPOSITS OF THE MOHAVE REGION AND MARINE TERTIARY BEDS OF SAN JOAQUIN VALLEY, CALIFORNIA[3]

BY JOHN C. MERRIAM AND ROBERT W. PACK

(*Abstract*)

In the formations of the Mohave region numerous mammalian remains have recently been found. The fauna of the Mohave region is most nearly allied with that of the Upper Miocene formation in the western border of the Great Plains region.

The continental deposits of the Mohave region extend to the foot of the mountain range to the east of Tehachipi. The great marine and fresh-water series of the San Joaquin Valley lies on the west flank of the range only a short distance from the most westerly exposure of the Mohave beds. Recently R. W. Pack has obtained from marine Tertiary beds in the Tejon Hills, on the west flank of the range, a small collection of vertebrate remains. This collection includes the phalangeal elements of Merycodus, a small deerlike form, similar to a species known in the Mohave beds, and teeth of a horse similar to *Merychippus calamarius* of the Mohave region. Associated with these remains are shark's teeth and a number of marine shells. The known invertebrate fauna of these beds has been presumed to indicate their Lower Miocene age. The question arises as to whether the mammal-bearing beds of the eastern border of the San Joaquin are of the same age as the presumed Lower Miocene of the Kern region, or whether there is a discrepancy between the age determinations based on the one hand on mammalian fossils judged by comparison with the Great Plains faunas, and on the other hand on marine forms compared with those of the Atlantic coast.

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[3] Presented by permission of the Director of the U. S. Geological Survey.

The following paper was read by title:

THE BIOGENETIC LAW ILLUSTRATED IN THE DEVELOPMENT OF FOSSIL CEPHALOPODS

BY JAMES PERRIN SMITH

(*Abstract*)

Recapitulation is discussed and illustrated and examples of unequal acceleration pointed out. Arrested development and retardation are discussed as factors in the biogenetic law. Cases of convergence are brought forward and their bearing on orthogenesis touched upon. The conclusion is reached that imperfect recapitulation is all we may hope to find in the ontogeny of any highly organized group.

FAUNAL RELATIONS OF THE UPPER NEOCENE IN THE SARGENT OIL FIELDS, CALIFORNIA

BY BRUCE MARTIN

(*Abstract*)

The results of recent work in this field and the close faunal relations with the Etchegoin formation of the Coalinga region were discussed.

DISCUSSION

Mr. Lawson called attention to Mr. W. F. Jones's work in this region, saying that Mr. Jones presented the first evidence of marked orogenic disturbance in the time between the Monterey and the Etchegoin-San Pablo deposition in central California.

Mr. Clark spoke of the great transgression of the Etchegoin sea after Santa Margarita time.

Mr. Anderson thought the Etchegoin of the Sargent locality was very likely directly connected with that of the Coalinga region.

Mr. Merriam emphasized the close relationship between the Purissima and Etchegoin formations, as shown by their fossils.

MONTEREY SERIES ON THE SOUTH SIDE OF MOUNT DIABLO, CALIFORNIA

BY W. S. W. KEW AND R. C. STONER

(*Abstract*)

The Monterey series of this region has a thickness of 1,800 feet, consisting of conglomerates, sandstones, and shales; the lower part is quite conglomerate, but there is no evidence of angular unconformity with the underlying Tejon. The Monterey series is here unconformable beneath the San Pablo. A considerable fauna has been collected showing that both Upper and Lower Monterey time is represented.

SAN PABLO FORMATION ON THE NORTH SIDE OF MOUNT DIABLO, CALIFORNIA

BY BRUCE L. CLARK

(*Abstract*)

The San Pablo formation, on the north side of Mount Diablo, has a thickness of about 600 feet. It lies unconformably on the Monterey series and is overlain unconformably by the Pinole tuff. The formation consists of conglomerates, coarse sandstone, and a minor amount of shale, all representing very close inshore deposits. In the middle of the San Pablo there are evidences of land conditions. A fauna of 20 species of invertebrates has been collected from the Monterey series just below the San Pablo and about 60 species from the San Pablo.

FAUNAL ZONES OF THE SAN PABLO FORMATION EAST OF WALNUT CREEK, NEAR MOUNT DIABLO, CALIFORNIA

BY JOHN P. BUWALDA

(*Abstract*)

Discussion of a measured section of the San Pablo formation on the western side of the Mount Diablo anticline, with the results of a study of the faunal zones.

PRELIMINARY INQUIRY INTO THE GEOLOGICAL SIGNIFICANCE OF ROCK-BORING SHELLS

BY ALBERT L. BARROW

(*Abstract*)

This inquiry is undertaken in order to learn what facts the habits of living rock-boring shells may contribute to explain the conditions of deposition at unconformities where fossil rock-boring shells are now found.

While animals which bore into rock are found among nearly all the large groups of invertebrates, the Pelecypod borers are far more numerous along the Pacific coast than borers of any other class. The many genera of Pelecypoda which burrow into mud or sand are of little value in this inquiry. On account of their peculiar habit of boring into fine-grained rocks along the exposed portions of the shore, in a zone extending only a few fathoms below the low-tide level, the several rock-boring genera of the *Pholadidæ* and the genera *Adula*, *Lithodomus*, *Petricola*, *Saxicava*, and *Platyodon* have a very definite significance. The nestling shells of the genera *Tapes*, *Saxidomus*, and *Panopea*, associated with the borers, are of importance.

The remains of marine animals which are known to habitually bore into rock is evidence of an unconformity, because it presupposes the existence of a firm bed in an earlier formation, hard enough to attract the borers, before the overlying beds were laid down. Subsequent crustal movements were upward if the holes are found to have been eroded or filled with terrestrial deposits, or downward if filled with marine deposits. The nature of the over-

lying beds indicates to a certain extent the depth of submergence and the distance to which the shoreline may have retreated. Contacts containing boring shells, moreover, show the location of the headlands and open coast along the ancient sea margin.

DISCUSSION OF THE JURASSIC AGE OF THE SLATES AT SLATE SPRINGS, MONTEREY COUNTY, CALIFORNIA

BY CHARLES H. DAVIS

(*Abstract*)

The slates of the Slate Springs beds dip unconformably under the basal Knoxville, as described by Dr. H. W. Fairbanks. The Lower Knoxville is placed by some geologists in the Upper Jurassic.

The species from Slate Springs are very similar and in five instances out of eight are practically identical with described Jurassic forms. None of the species are unlike Jurassic forms. Six of the eight species listed from Slate Springs are identical, or nearly identical, with species described from the Queen Charlotte Islands, British Columbia. The Queen Charlotte Islands beds have been definitely correlated by Stanton with the Enockin formation of Alaska which he calls Upper Middle Jurassic. The above considerations appear to place the Slate Springs (Franciscan?) beds in an age not higher than the lower Upper Jurassic.

PRELIMINARY REPORT ON THE TERTIARY PALEONTOLOGY AND STRATIGRAPHY OF SOUTHWESTERN WASHINGTON

BY CHARLES E. WEAVER

(*Abstract*)

Marine strata of Eocene, Miocene, and perhaps Pliocene age, with a total maximum thickness of about 30,000 feet, are found in southwestern Washington. The sediments along the north coast of Washington form only a thin fringe from Cape Flattery eastward, but are found west of the Cascade Mountains from the Columbia River to Cape Flattery.

The Eocene is found west of the Cascades and in the Puget Sound Basin from Seattle to near the Chehalis River. There were great fluctuations of land and sea and outpourings of basaltic lavas during the Eocene. West of the Cascades the lavas are interbedded with marine sediments, and the later fauna is typically Tejon, while the older fauna's position is not yet determined. Toward the east brackish-water beds, constituting the Puget group of Willis, prevail and are probably the equivalent of the marine Tejon farther west. The Roslyn of central Washington is probably equivalent to the marine Tejon. The lavas are not found in the Olympic Peninsula. The coal of Washington is almost entirely confined to the Tejon horizon. Igneous activity ceased entirely at the close of the Tejon.

There is a distinct unconformity between the Tejon and the overlying beds carrying a fauna akin to that of Dall's Astoria beds. Above this unconformity are 10,000 feet of beds, with two faunas, that of the upper beds being quite distinct from that of the lower. The Upper Miocene is similar to the San Pablo.

From the Columbia River to Cape Flattery is a series of northwestward-pitching synclines, and 19,000 feet of beds are well exposed in continuous section. In the Grays Harbor region there is complicated structure with much folding.

EVIDENCE INDICATING AN UNCONFORMITY AT THE BASE OF THE TAMIOSOMA ZONE IN THE COALINGA OIL FIELD, CALIFORNIA

BY JOHN H. RUCKMAN

(*Abstract*)

That an unconformity exists at the base of the Tamiosoma zone seems established by overlapping, irregular contacts, *Pholas* borings, and underground structure. The apparent gradation into the lower beds at the northern end of the section is probably explained by the fact that the conglomerates of the "Big Blue" were worked over and redeposited at the base of the Santa Margarita with little change. The line of contact therefore probably runs somewhere through the conglomerate.

The position of the unconformity, a short distance below the *Astrodapsis whitneyi* beds, corresponds closely to the unconformity in the San Pablo of Mount Diablo, but the unrecorded interval may also include the lower San Pablo.

DISCUSSION

Mr. Taff said that he had long suspected this unconformity from the field relations.

The following paper was read by title:

CONTRIBUTIONS TO AVIAN PALEONTOLOGY FROM THE PACIFIC COAST OF NORTH AMERICA

BY LOYE HOLMES MILLER

(*Abstract*)

The paper is an effort to assemble and to harmonize the results obtained in study of fossil bird remains from the Pacific coast of North America. Brief papers by Cope and by Lucas and a somewhat extended account by Shufeldt are reviewed. The main body of the paper is based upon a personal study of the collections at the University of California. Nine geologic horizons are represented in the remains discussed. All but three species recorded are from deposits of Pleistocene age. The great range of conditions under which remains were entombed as well as the variety of topographic conditions represented make the concept of the Pleistocene avifauna unusually complete. The families Cathartidæ and Falconidæ are especially rich in fossil species. Problems of distribution constitute one of the prime interests. A total of fifteen fossil species show their closest relationship to forms at present restricted to more southern ranges. Various suggestions as to the causes of extinction are discussed and a tabular view of the Pleistocene avifauna of the Pacific coast is presented. The number of species recorded is 120.

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PLEISTOCENE GEOLOGY OF NEW YORK STATE

ANNUAL ADDRESS OF THE PRESIDENT, HERMAN L. FAIRCHILD

(*Read before the Society December 28, 1912*)

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INTRODUCTION

The primacy of New York among the States in population, wealth, manufacture, and commerce is based on its physical characters—geologic structure, physiographic relief, and geographic relations. New York State has the greatest range and perfection in its stratigraphic series and the greatest variety in physiographic features. In scenery other States may possess single features of surpassing grandeur and beauty, like the Colorado Grand Canyon, Yosemite Valley, Crater Lake, the mountains of the Cordillera, or the snow-capped volcanic cones of the northwest, but for abundance and variety of beautiful scenery of educational value New York may claim first place. In the variety and excellence of Pleistocene phenomena the State probably excels any other equal area of the earth's surface. This is due to the varied and unusual physiography, combined with a favoring attitude of the area in relation to the continental glacier. The features of special excellence occur largely in the western part of the State. These are the series of more than twenty parallel, north-sloping valleys which hold the unique series of twelve so-called Finger lakes; the remarkable succession of glacial lakes in the Ontario drainage area; the conspicuous, abandoned channels of the rivers that drained those lakes; the surpassing display of drumlins, of kames and eskers; the fine series of moraines, and the large number of postglacial ravines.

The purpose of this writing is to utilize this remarkable display of Pleistocene phenomena in illustration of the glacial history and in brief discussion of some problems in the philosophy of glaciation.

MULTIPLE GLACIATION

The accepted facts of multiple glaciation in the Mississippi Basin, coupled with proofs of pre-Wisconsin drift in Pennsylvania and New Jersey and on Long Island, with accumulating evidences in New England, demands the theoretical acceptance of at least dual glaciation for New York State. But the positive proof, in the field, of a pre-Wisconsin ice-sheet has not been found. In several localities the deeper till is so unlike the upper till that it strongly suggests a separate origin. Some singular topographic features are not satisfactorily explained without appeal to the earlier ice-invasions. The Rutland Hollow, east of Watertown, is an example. Many erosion features, specially in the St. Lawrence District, seem inconsonant with the work of the latest ice.[1] However, we have found no example of interglacial or warm-climate deposits interbedded in the till. Such should be expected and sought, but at present we can only say that multiple glaciation in New York, at least north of Long Island, is quite certain in our philosophy, but that it remains unproven in observation.

Although our glacial phenomena in New York are doubtless not the effects of merely the latest or Laurentian ice-sheet, the latter so strongly dominates that for purpose of this writing it is impracticable to attempt discrimination, and unless specially noted it will be understood that reference is to the latest, or Wisconsin, glaciation.

LAURENTIAN (LABRADORIAN) ICE-BODY

LIMITS IN NEW YORK

The reach or extent of the latest ice-sheet has long been known in a general way through the early work of Upham, Lewis, and Wright in tracing the terminal moraine. In later years the stretches of the terminal moraine which lie in New York have been reexamined, on Long Island by Woodworth and Fuller and Veatch and in Cattaraugus County by Leverett. There are two small areas in the State which the ice-sheet did not cover, the south side of Long Island and the district partly inclosed by the northward bend of the Allegany River.

THICKNESS

At its maximum the ice-sheet covered the highest points in the State, the Adirondack (5,344 feet) and the Catskill (4,205 feet) mountains. Judging from the Antarctic and Greenland ice-caps, the surface of the Laurentian shield was a low dome of fairly uniform curvature, uninfluenced by the irregularities of the submerged land surface. Our only means of estimating the thickness of the ice-cap is by assuming a gradient of the surface slope, as suggested by observations on the existing polar ice-fields. Such data, however, can be safely used only in a suggestive way when applied to the Laurentian ice-shield because the difference in latitude must be an important factor. The border of our ice-field, in latitude 41 to 44 degrees, was subjected to so much greater solar radiation and consequent higher temperatures, with heavy precipitation and rains, that it must have had increased plasticity and resultant mobility, giving the surface slope diminished gradient. But, on the other hand, the snow supply over the central area or alimentation ground of the ice-field must have been greater than over the polar fields, which might give greater depth and steeper gradients toward the interior of the field. The anticyclonic winds over the ice-cap, recently emphasized by Hobbs, would brush the snow toward the borders of the field and so tend to reduce the surface slope of the interior.

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[1] For discussion of this subject see New York State Museum Bulletins, No. 145, pp. 164-172; No. 160, pp. 17-18.

Shackleton found that the great outlet glacier in Antarctica, named the Beardmore, had a rise of 60 feet per mile for 100 miles, with declining rate inland, attaining about 11,000 feet in 275 miles, or 40 feet per mile for the entire distance. If we assume a slope of 60 feet per mile for the glacier surface over western New York, it gives an altitude of over 9,000 feet on the area of Lake Ontario, the margin of the ice-sheet lying at near 2,000 feet altitude. Over central New York (district of Oneida Lake) the altitude would be about the same, and if to this we add 30 feet per mile to the middle of the Adirondacks it gives 3,000 feet more, or over 12,000 feet altitude. If we assume 40 feet per mile on the Hudson-Champlain meridian it gives 12,500 feet of ice on the Canadian boundary. Thirty feet per mile gives over 9,000 feet of ice. These figures may be somewhat excessive, but they at least prove the fact of a great thickness of solid water piled over the State. The effect of such weight will be noted later.

MOVEMENT

The ice-mass had a spreading or radial flow, as a plastic body, due to its own weight. The prevailing direction over New York was southwestward, except that in the lower Hudson Valley the flow was southward, conforming to the valley. The waning or thinning ice-sheet was deflected by the larger topographic relief, and when the ice-mass resting over the Ontario Basin ceased to be impelled by thrust from the northeast it developed a spreading flow, radiating from the area now occupied by Lake Ontario. This is well shown by the orientation of the drumlins in the Ontario Basin. A good illustration of valley diversion is shown in the maps depicting how the Hudson lobe and the Ontario lobe pushed into the Mohawk Valley from opposite directions, impounding glacial waters between them. As the direction of flow near the margin of the ice-sheet must incline to right angle or normal to the ice-front, the direction of latest movement in any district can be approximately known if the ice limit is determined. The series of maps accompanying this writing show several stages in the waning and disappearance of the ice and suggest the direction of flow at different positions.

RECESSION

The set of maps[2] prepared for illustration of this address give fifteen positions of the ice-front during its recession across the State. A larger number could be depicted, but only those have been selected which have some significance in the lake and drainage history. The criteria used in locating the ice-front positions are the moraines and the ice-border river channels, the latter correlating with lake levels and shore features.

The recession of the ice-front was certainly not steady or continuous, but must have had considerable oscillation, readvances, and re-retreats. The heavier belts of moraine and the lines of long-lived ice-border drainage probably represent readvanced positions.

The length of time represented by the passage of the ice-front across New York is unknown, but is certainly scores of thousands of years. Probably 100,000 years is not too long. We may not judge the rate of waning by the present behavior of the ice-fronts in Greenland and Antarctica, as the climatic factors due to difference of latitude must have been effective. If the oscillations of the ice-front were due to any irregular or nonperiodic variations of climate, then we can have no idea of the time involved either in the advance or the waning of the ice-sheet; and the only periodicity in climatic factors now recognized that seems adequate is the precession of the equinoxes, having a variable but average period of about 21,000 years. Taylor has studied the Cincinnati-Mackinac moraine series from this viewpoint, and concludes that the fifteen rather equally spaced moraines represent 75,000 to 150,000 years, using the minimum length of the precession period.[3] The eight or ten morainic belts which we now recognize in western New York may correlate with that many on the Cincinnati-Mackinac meridian, but the recession of the ice-front on the Hudson-Champlain meridian probably represents a much longer time than the Ohio-Michigan series.

If the changes in geologic climates be due to variation in solar radiation it is conceivable that some minor secularity might be responsible for the oscillations of the ice-front. Variation in the amount of carbon dioxide content of the atmosphere can more reasonably be invoked to explain the larger and more irregular changes in ancient climates than for the shorter and more regular changes that caused the ice-front oscillations. The same is true of continental elevation as a cause of colder climate.

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[2] The maps are omitted in this publication.

[3] Journal of Geology, vol. 5, 1897, pp. 421-465.

Geologic Effects of the Ice-sheet

EROSIONAL WORK

The subject relating to glaciers that has been the cause of the greatest difference of opinion is the erosive power or destructional work. The writer will here not discuss seriously glacial erosion in general, but only so far as it applies to New York.[4]

That mountain glaciers abrade their valleys and by moderate erosional work change the V-shape to the U-shape has long been apparent. The destructive work at the head of the glacier in production of cirques is fully recognized, although this is largely atmospheric effect. All argument for deep erosion by glaciers based on the abrasional or plucking action of mountain or stream glaciers fails when applied to New York, as there were no effective mountain glaciers in New England and New York, at least not during the waning of the Laurentian ice-body. The ice disappeared from the more elevated tracts while lingering in the lowlands.

Whatever the erosive power attributed to mountain glaciers of Norway or New Zealand it can not be invoked here, as New York had no such glaciers. We have to consider only the work of a continental glacier. Whatever destructive effects an ice-cap may have under its central or subcentral mass, it has long been admitted that it is not a vigorous erosive agent in its border zone or dissipating belt. The district in New York, the Finger Lake area, which has been used in illustration of glacial valley erosion, was always in merely the outer zone, or that of predominant deposition by the Laurentian glacier. All students of New York geology practically agree on the lack of vigorous ice erosion over all the rest of the State. Those who have worked in the Adirondacks and in the Champlain and St. Lawrence valleys have noted the proofs of weak erosion.[5]

It has been shown by Gilbert and the writer that erosion was weak on the Ontario lowland of western New York. The claim for deep erosion has been only for the valleys of the Finger lakes, specially Cayuga and Seneca, the claim based chiefly on anomalous topographic features.

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[4] For the argument in general see Bull. Geol. Soc. America, vol. 16, 1905, pp. 13-74.

[5] See New York State Museum Bulletin, No. 145, 1910, pp. 147, 171-172.

The advocates of glacial deepening of the valleys appeal either to vigorous currents at the bottom of the ice-sheet or to the tongue-like lobations of the ice-front, to deeply gouge the bottoms of the valleys so as to produce hanging side valleys and "oversteepening" of the lower slopes of the main valleys. The existence of effective basal currents in the region under consideration seems highly improbable. The general land slope was opposed to the ice-flow—that is, the ice was moving on an upslope. The lower or basal ice was very heavily burdened with rock rubbish, and would naturally serve as the bridge over which the upper ice traveled, partly by shearing and partly by superior plasticity. But if for argument we grant the existence of effective bottom currents, then we are forced to concede that under the conditions of great vertical pressure, with the movement on an upslope in soft shale rocks, the erosion would have to be by abrasion and not by plucking. At its intensest, abrasion must be a slow and a self-checking process. Long ago Russell emphasized the fact that plasticity of the ice is reduced in proportion to its burden of drift. Admitting this, it follows that an excess of rock stuff in the basal ice, the inevitable result of heavy erosion, would produce stagnation. Moreover, the excessive product of grinding would serve as a buffer to protect the bedrock, just as a stream full loaded with detritus ceases to erode.

If the lobations or valley tongues of the ice margin had any erosive effect comparable to mountain glaciers, such work should have been greatest south of the land divide, or where gravity directly assisted the flow. But the conspicuous lack of erosive work on the uplands and south of the divide is frankly admitted. In description of the area covering the eight quadrangles of the Watkins-Ithaca-Elmira-Owego District, in the U. S. Geological Survey Folio 169, Professor Tarr, who was the leading advocate of glacial erosion of the Finger Lake valleys, wrote:

> "In harmony with this evidence of slight erosion is the fact that the mature upland divide areas have suffered notable modification only by deposition and not at all, so far as can be seen, by ice erosion" (page 16).
>
> "In the southern half of the area glacial erosion was not sufficient to remove the products of preglacial decay from the hills, nor, so far as any evidence goes to show, to modify perceptibly the topography even of the valleys" (page 31).

North of the divide the lobations of the ice-front were pushed up the valleys by the pressure of the ice in their rear, and were so heavily loaded with drift that they were not eroding but depositing. The fact of superload of drift is clearly shown by Tarr's map of the surficial geology.

South of the divide morainal drift is almost entirely lacking in the south-leading valleys and only scantily represented in the larger east and west Susquehanna and Chemung valleys. Tarr says:

> "On the upland, south of the area of the recessional moraines, little moraine material is found and no definite system has been worked out.
>
> "The complex of moraines in the northern part of the Watkins Glen quadrangle and the northwestern part of the Catatonk quadrangle, contrasted with the general absence of moraines in the southern half of the area, forms one of the most striking features of the Quaternary geology" (page 17).

The heavy morainal drift in the valleys north of the divide was not derived from erosion of those valleys, but was the accumulated rock rubbish acquired by the lower part of the ice-sheet during its entire journey across the State. When the ice was thick enough to override the divide and flow south, it was the superficial, drift-free ice that passed across, while the lower, drift-loaded and relatively stagnant ice reposed in the Ontario Basin and its valleys, serving as the bridge, that was overriden by the clearer and more plastic superficial layers. In evidence of this is the relative absence of drift south of the divide and the almost entire absence of crystalline rocks or far-traveled material. Quoting Tarr:

> "In the uplands south of the recessional moraines foreign fragments are much more rare, and in some parts of the uplands a careful search is required to find even a small pebble of crystalline rock, while boulders are practically absent" (page 16).

To whatever extent the ice in the margin of the snowfield was produced by the centrifugal, anticyclonic winds from the interior of the ice-cap, as suggested by Hobbs from study of the existing continental glaciers,[6] it also favored lack of drift in the periphery of the ice-body. With the waning and thinning of the ice-cap the drift-loaded lower ice was finally uncovered so as to constitute the marginal belt, and was then subjected to thrust or push from the thicker body on the north. At this stage the heavy moraine deposits were made in the valleys, producing the present drainage divide, and the lobations of the ice-front built the concentric lateral terminal ridges north of the divide. At a later stage of the waning, when the required factors were properly combined and balanced, the drumlins were constructed on the lowlands, northward.

Many facts are cited by Tarr showing the impotency of the latest ice-sheet, and he finally admitted that the "Wisconsin ice-sheet failed to notably modify the topography in the greater part of this area" (page 16).

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[6] Characteristics of existing glaciers, 1911.

This would seem to terminate the debate about glacial erosion in the Finger Lake District. But it does not, as the responsibility for the anomalous topography is shifted back to the pre-Wisconsin glaciers.

> "This carries with it the necessity of believing in 1,500 feet of vertical erosion in the Seneca Valley by the continued ice-work of at least two periods of glacial occupation, separated by an interval of gorge cutting several times as long as the postglacial interval" (page 16).
>
> "The statement is warranted, therefore, that these valleys have been profoundly modified by glacial erosion, both by deepening and broadening" (page 30).
>
> "But here, as in the process of glacial stream erosion, the bulk of the work was done by an earlier ice advance" (page 31).

It is admitted that ice-sheets may have some individuality, and that successive sheets on the same territory may have somewhat different behavior and produce different effects due to differences in the climatic, topographic, and drift factors; but it does not seem reasonable that one ice-sheet could deepen Seneca Valley 1,500 feet, while its successor did practically no eroding at all. If the pre-Wisconsin ice-sheet had such remarkable excavating power, it should have produced conspicuous erosional effects elsewhere than in the valleys, and specially in the southern part of the State, and should have piled heavy "old drift" deposits beyond the reach of the Wisconsin ice.

The drift burden of the Laurentian ice-sheet is represented not merely by the mass of the moraines and the volume of detritus carried away by the glacial drainage, but also by the enormous bulk of drift built into the drumlins. Even if the drumlins were partly constructed by the earlier ice-sheet they can not, because of their location, represent any product of deep erosion of the sections of Seneca and Cayuga valleys in question. There are no heavy moraine deposits south of the Valley-Heads moraine, for the terminal moraine is not massive, and the ancient drift in Pennsylvania and New Jersey is not excessive in volume. The only other disposal of the great volume of debris that should have been produced by deepening of the valleys 1,500 feet must have been by outwash of the glacial drainage. But when the valley-train and outwash deposits attributed to the latest ice are considered there is no very large volume left to represent any earlier drainage.

The entire argument for deep ice erosion in the Finger Lake region is based on physiographic features, hanging valleys and "oversteepened" valley walls. The writer believes that sufficient attention has not been given to the effects of pre-Pleistocene drainage in connection with the climatic, topographic, and diastrophic factors. The high elevation of the northern part of the continent in Tertiary time seems to be a fact and accompanied by warm climate. If necessary to explain phenomena we may assume effective vertical movements in our region. The Tertiary was certainly a time of vigorous drainage and remarkable valley-cutting in northern lands. When the fiord valleys were making in other lands what was doing here? Undoubtedly our rivers were also active, and the deep valleys of central New York are one result.

At the last Baltimore meeting of the Society the writer exhibited a series of maps suggesting the drainage evolution in New York.[7] The high "hung-up" valleys, with northeast by southwest direction, and mostly without present streams, seem to be an inheritance from the primitive drainage on the new land surface. The drainage lines of the upper tributaries to the Delaware and Susquehanna rivers preserve their original direction. During some pre-Pleistocene time the development of subsequent valleys along the strike of the thick and weak Ontario strata resulted in a great east and west valley carrying a great trunk stream, the hypothetical Ontario River. Into this valley was drawn from the south, as obsequent streams, all the drainage of western and central New York and the adjacent territory of northern Pennsylvania. The Susquehanna River turned northward at Elmira and occupied the Seneca Valley, which probably accounts for the excessive depth of the valley, a drilling at Watkins of 1,200 feet failing to reach rock. The Genesee River is the one stream which fully represents the preglacial northward flow, having held its northward direction clear across the State in spite of the tendency of glaciation to force it into southward flow. All the other drainage of south-central New York was forced to southward escape, mostly in tribute to the Susquehanna and through the new rock gorge at Towanda, Pennsylvania. A late and probably rapid land uplift, rejuvenating the obsequent drainage, will probably be found to satisfactorily account for the great depth and other anomalous features that have been used as arguments for deep glacial erosion in New York. Interglacial drainage may be important in this work.

It will now be understood that when the earliest ice-sheet invaded New York it found a topography unlike the present—a remarkable series of parallel, deep, open, north-sloping valleys that headed southward, the larger ones in Pennsylvania. The present divides in the valleys are due to the moraine fillings left by the ice. The deep canyon-like valleys were occupied by the glacier and some abrasion and smoothing of the walls was inevitable. But it should not be forgotten that the ice-tongues in these valleys were not mountain glaciers, but merely lobations of a drift-burdened margin of an ice-sheet moving on an upslope. Conceding some erosive power to the ice-tongues in the valleys, then, instead of deepening the valleys and oversteepening the walls, and so producing the present convex cross-profiles, they should have cut the walls and widened the valleys and produced concave profiles. In the work of stream glaciers convexity of valley slope is succeeded by concavity. In final word to a discussion already too long, in the opinion of the writer all the facts and philosophy of ice erosion argue against deep glacial erosion in the Finger Lake valleys.

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[7] Bull. Geol. Soc. America, vol. 20, 1910, pp. 668-670.

One interesting product of glacial erosion is to be noted. These are some hills which have the form and attitude of true drumlins, but which are composed of soft shale, shaped into drumlin form. These rocdrumlins will be described later.

CONSTRUCTIONAL WORK

Subglacial: drumlins.—The general drift sheet presents no special features meriting description at this time. The important subglacial deposits are the drumlins. New York State probably has the best display of these interesting hills of any district in the world—in number, variety of form, variety in orientation, difference in composition, and in the clear relationship to the correlating moraines.

Much space might be given to description of these singular and most beautiful hills, but they have already been quite fully described in a bulletin of the State Museum.[8]

Possibly in other regions there may be drumlins produced by the ice overriding and reshaping moraines, but all the true drumlins observed in New York are certainly constructional in their origin. The New York moraines are mostly water-laid drift, specially north of the divide, the debris in the ice being largely grasped by the glacial drainage. If the drumlins were moraine accumulations they would have morainal composition and structure. On the contrary, they are very compact till, distinctly bedded with concentric structure. The best exhibition of the bedding is shown along the shore of Lake Ontario, between Sodus and Oswego, where the undercutting by the waves has dissected numerous drumlins from top to bottom and in different directions. Sand or gravel within the mass of the drumlin is of infrequent occurrence, though some of the drumlins between Clyde and Savannah hold considerable sand in their superficial layers. Many drumlins exhibit decided difference between the deeper and the superficial till, sometimes so pronounced as to suggest two epochs of construction.

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[8] New York State Museum Bulletin, No. 111, 1907.

Along the belt of outcrop of the soft Salina shales there are drumlins which have a shale base, and perhaps some with a shale core. Fifteen miles northwest of Syracuse and west of Baldwinsville the drumlin forms are entirely shale. The deeply weathered clay rock supplied to the ice-sheet a plastic material similar in its behavior to the ground moraine. These hills are not true drumlins. They are wholly erosional in origin, as indeed are the true drumlins in their shaping. We have called them rocdrumlins, using the Celtic prefix. It is possible that similar forms will be found in the Champlain-Hudson Valley, shaped out of the softer Ordovician shales. The ice-sheet does not appear to have had scraping force sufficient to shape into the drumlin curve any rock hills of harder materials than soft shale, though bosses of crystalline rocks in the St. Lawrence Valley and other districts of long-continued abrasion are rounded and smoothed on the struck sides.

The mechanics of drumlin construction is a complex problem. The required cooperation and balancing of several dynamic factors make the drumlins exceptional features even in the glaciated territory. The more important constructional factors appear to be: (1) an excessive amount of drift; (2) the drift of clayey or adhesive and plastic material; (3) such thickness of marginal ice and with such relation to the rearward ice-body that the whole depth of ice accepts a thrustal movement, producing a sliding motion of the ice in ground contact; (4) such temperature or physical condition as to allow plasticity and some differential motion within the ice, essential for the overriding of the growing obstruction instead of its removal. Here is found a singular balancing of two opposing factors—rigidity and plasticity—rigidity holding the ice-mass as a whole to its thrustal motion, while at the same time bands or currents within the ice-sheet have unequal motion, permitting the curving or arching flow over the growing hill of drift. The drumlin-making process appears to be a plastering on and a rubbing down, depending on the condition of more friction between clay and clay than between clay and ice. The resulting form of the growing obstruction is that which offers the greatest resistance to removal or the least resistance to the passage of the ice over it. The molding action of the ice-sheet is well shown by the minor ridges in some districts; the secondary and tertiary inferior ridges lying on the flanks of or between the primary ridges suggest the wood molding struck in the planing mill.

The complex of forces and conditions necessary for drumlin construction explains their peculiar distribution, orientation, and form. In the western half of New York the rich display of drumlins (nearly a thousand ridges being shown by the contours on the Palmyra sheet alone) is practically limited to the territory north of the divide, where the drift was profuse and the thinning ice was pushing on an upslope. In the Ontario Basin their attitude or direction of the major axis is radial to the middle of the basin, varying from due east to southwest. In the Erie Basin a group about Chautauqua Lake points southeast, while in the Mohawk Valley north of Richfield Springs a group has westward pointing. In the Champlain and Hudson Valley the drumlins point southward. In the St. Lawrence Valley they show a spreading flow. Everywhere they show the later ice-flow direction.

The most typical drumlin form, that which seems to express the most vigorous action and effective balancing of the several factors, is an elongated oval, with steep convex side slopes, and these are found in the middle of the drumlin belt. New York exhibits all possible variations from this form. The shorter ridges, sometimes approaching dome-shape, but usually with some irregularity or lack of symmetry, are found at the north or proximate side of the drumlin belt, which suggests that the broad form is the product of less perfect work. The much elongated and attenuated ridges lie at the south or ultimate side of the belt, and indicate the more uniform or rigid flow of the ice-sheet with deficiency of drift.

In the western end of the State the till sheet over large areas has been rubbed into a fluted or washboard form on a large scale, but with low relief. It is inferred that this drumlinized surface, with ribs one-fourth to one-half mile wide, represents the work of thick ice having great weight and vertical pressure, with diminished plasticity and carrying only a moderate load of drift. The direction of the flutings, southwestward, is the direction of flow of the maximum ice-body.

In central New York we have been able to definitely correlate the drumlin belt with its synchronous moraine; to determine the position of the ice-front during the drumlin-making episode. On the meridian of Seneca and Cayuga lakes the drumlins of the north side of the belt are more scattering and irregular in form. In the middle of the belt they are close-set, typical elongated ovals. Southward they become close-set ridges with secondary flutings, while at the south edge of the belt they are slender ridges and flutings, too attenuated to be represented by the 20-foot contours of the topographic sheets. It would require at least 5-foot contours to show the frontal drumlinized surface. Two miles in front of the most southerly ridges indicated on the Geneva sheet lies a weak but definite moraine. It is weak because the ice had plastered its load of drift into the drumlins.

From the relation of the ice-front to the glacial waters and other data, it has been roughly estimated that the thickness of the ice over the middle of the drumlin belt was about 900 feet, or more than 700 feet over the tops of the highest drumlins.

Marginal: moraines.—The only map published to the present time that shows moraines in detail is that by Tarr in the Watkins Glen-Catatonk Folio (No. 169), which is accompanied by good description. This map, Surficial Geology, covers eight quadrangles of the south-central portion of the State, and includes the upper (southern) ends of the Seneca and Cayuga valleys. Except a few fragmentary moraines in the east and west stretch of the Susquehanna and Chemung valleys, there are almost no moraines south of the divide, as already noted in this writing. The lines of drift massing show decided lobation of the ice in the valleys north of the divide and conformity to the land surface. The plastic ice was here flowing on its own deposits and had no erosive power. Probably the only moraines in the State that can properly be called "lateral" lie in these valleys.

In the west half of the State the heavier or more conspicuous morainic belts have been approximately located, though little precise mapping has been attempted. The most recent and definite is by Leverett,[9] and a sketch cap, figure 11, page 15, in the Folio 169. These morainic belts clearly show the larger lobation of the waning ice-sheet in the Ontario and Erie basins.

In the east half of the State the moraines have been located in only few places, excepting the terminal moraine. In the Hudson and Champlain Valley Woodworth has recognized some fragments and ice contacts. This difference in moraine development between the two parts of the State is due to the difference in the gross topography. A glance at the map shows that on the Hudson-Champlain meridian the distance covered by the receding ice-front is greater than in the Ontario Basin, so spreading the drift over more area. The rocks in the east part of the State are more resistant to erosion, due to kind and structure. The Hudson ice-lobe and its successor in the Champlain Valley were always faced by ocean waters, and the terminal drift in the bottom section of the great valley was mostly scattered and buried under the water deposits. On the high grounds east and west of the marine inlet the surfaces are so rough, or even mountainous, that the moraine deposits lack continuity and volume. It will be very difficult to trace morainic belts across the Hudson-Champlain Valley with certainty, though it is important to know the lines of the receding ice-front.

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[9] U. S. Geological Survey, Monograph XLI, 1902.

WORK OF GLACIAL WATERS

STREAMS: EROSIONAL

Normal drainage.—It is apparent that the flow of glacial waters freely away from the ice could occur only south of the divide, and as the present divide was established by morainal filling and lies north of the preglacial divide, much of the southward flow was drainage of ice-dammed waters, and that some of the present south-leading channels were cut by the glacial waters. The preglacial flow of the main streams was northward, but the tributaries had various directions. The glacial drainage took advantage of the favoring valleys and connected them into sequence of southward flow. Tarr thought that the work of stream diversion and of channel erosion was mainly pre-Wisconsin for the district described in the Folio 169 (page 30). He specially cites the outlet of Cayuga Lake, the gorge of Tioughnioga Creek, and the gorge of Chemung River behind Hawes Hill, west of Elmira. The copious waters from the waning Laurentian ice-sheet were supplied with such volume of detritus that they were largely aggrading agents. It is possible that the south-leading valleys were mostly established by pre-Wisconsin glacial drainage, and that the work of the latest glacial floods was chiefly transportative. In the eastern half of the State the glacial outflow was freely into the Susquehanna and Delaware escape or into the Hudson-Champlain marine inlet, so there was no necessity for cutting new channels.

The heaviest normal drainage was that in south-central New York, concentrated in the Susquehanna, which cut the gorge south of Sayre, Pennsylvania, and the river which drained Lake Iroquois through the Mohawk Valley, the Iromohawk. This great river was the predecessor of the St. Lawrence, which it probably exceeded in volume, as it carried not only the outflow of the glacial Great Lakes, but the copious waters from the glacial melting.

Subglacial drainage.—This class of glacial streams has been noted chiefly in relation to eskers, which fall under another head in this writing. It is not likely that all eskers were laid down in the beds of streams actually beneath or in tunnels under the ice-sheet, though some probably were. Probably most subglacial or englacial streams were fully loaded with detritus, and it is not likely that many streams beneath the ice margin were so free of drift or under such hydraulic pressure as to seriously erode their beds. However, a few peculiar channels or "dead" creeks have been noted which have such form and relations as to suggest erosional flow beneath the stagnant margin of the ice. One of these bayou-like channels is that of Dead Creek, a tributary of Seneca River, lying southwest of Baldwinsville and mapped on the Baldwinsville sheet.

Marginal drainage.—This class of drainage phenomena includes many of the most conspicuous and interesting features connected with the disappearance of the ice-sheet, and they have been the subject of much work by the writer. The ice-border drainage channels are important, as they locate ice-front positions and determine the altitude of the glacial lakes which they drained. They are humanly or economically important, since they have graded the ways for many lines of communication or transportation. And they are specially valuable for geologic instruction, since they are widely distributed and easily recognized products of long extinct agencies.

It is evident that stream-flow along the ice-margin could occur only where the land surface sloped toward the ice, and consequently only north of the divide. The remarkable physiography of the western half of the State favored the production of glacial lakes, which required outlet channels for the imprisoned waters.

The most notable series of ice-border drainage channels occur in five districts. (1) On the south slope of the Erie Basin, where the ice-impounded waters in the north-sloping valleys escaped westward into the Erian glacial lakes. (2) Along the south slope of the Ontario Basin the glacial waters found eastward escape toward the Mohawk-Hudson depression. (3) On the Helderberg scarp, west of Albany, the waters of the Ontario and Mohawk basins escaped southward into the Hudson marine inlet. (4) In the district about Rome, at the east end of the Ontario Basin, the waters both from the north and the west flowed along the sides of the ice-lobe to reach the Mohawk Valley. (5) On the north and west sides of the Lowville highland the waters of the southwestern Adirondacks and the Black Valley forced their passage into Lake Iroquois.

The channels leading east through central New York, more conspicuously developed in the Syracuse District, were the predecessors of Niagara River in their function, the equal of Niagara in volume and the rival of Niagara in cataract phenomena.

The successor of the Iromohawk and the immediate predecessor of the St. Lawrence was the outlet river of the second Lake Iroquois. This flowed across the north point of the Adirondack highland, at Covey Gulf, on the international boundary, with further flow in ice-border channels along the slopes northwest of Plattsburg, on the Dannemora and Mooers quadrangles.

STREAMS: CONSTRUCTIONAL

Subglacial: eskers.—The singular ridges of gravel, the laggard material in the beds of glacial streams, are well represented in the western part of the State and occur in the eastern part. Those lying in the northwestern section of the State have been studied, but the results are not published. Tarr describes in Folio 169 (pages 22-23) several which lie in the Susquehanna drainage territory and of large dimensions, and Carney recognizes nine on the Moravia quadrangle. Eskers may not occur on southward slopes, where the glacial streams had steeper gradient and free flow, but in localities where the ice-margin was comparatively stagnant and the drainage was sluggish.

The argument for subglacial origin of eskers finds some support in the New York examples. Tarr regarded some of those in the Susquehanna District as certainly made by subglacial streams. An esker four miles east of Clayton was deposited about 350 feet beneath the level of Lake Iroquois, which was laving the ice-front, and it is difficult to explain how it could have been constructed and its definite ridge form preserved unless it was built directly on the ground. The same argument applies to the Ingraham esker, north of Plattsburg.

Extraglacial: kames.—Isolated mounds of sand or gravel are usually embryo deltas of glacial streams, and are commonly associated with eskers. By linear multiplication they not infrequently grade into esker ridges.

As kames are built at the debouchure of glacial streams they indicate positions of the ice-edge. Areas of kames lie in belts of recessional moraines, and indeed constitute a large part of the New York moraines. The glacial debris which was not spread as the till sheet or rubbed into drumlins was largely gathered up by the drainage and dropped as some form of water-laid drift.

In western New York a few large kame areas are not closely connected or clearly associated with any conspicuous moraine belt, but, nevertheless, must represent recessional moraine. It is possible that some smaller kames might have been built by land drainage into lateral glacial lakelets, but detritus from land erosion must commonly have produced deltas or sand plains and be easily recognized by form and association. The great development of kames, at least in western New York, is north of the divide and they were built in the waters of the glacial lakes. This association with standing waters is so pronounced that it gives force to the idea that all typical kames are formed by streams debouching into water bodies, and sometimes by subglacial streams under hydraulic pressure. Streams debouching on the land would naturally produce either outwash plains or valley trains. The fact that basins or kettles, believed to be due to melting out of buried ice blocks, are usually abundant in areas of kames seems to prove that the materials were laid down in standing water in close association with the stagnant ice-margin, either on the ice or in hollows and valleys and reentrants in the ice.

Extraglacial: outwash plains.—These are the gravel and sand deposits spread out in front of the glacier by the outflow of the glacial streams and which can not be classed on the one hand as deltas or on the other as valley trains. Water-laid drift in facial contact or close association with the moraines and which can not be distinguished either as delta, kame, or valley train may safely be put in the indefinite class of outwash gravel plains. North of the divide where built in lakes they grade into deltas and kames. South of the divide they constitute most of the valley fillings, specially of the broader valleys which lay athwart the direction of ice-flow.

A not uncommon feature of the gravel plains, and one which shows the close relation to the glacier front, is the existence of ice-block kettles. The term "pitted plain" has been applied to the sand plains with numerous kettles. Another feature indicating their genesis is the preservation in some cases of the ice-contact slope. The outwash sand and gravel plains are more common in the southwest part of the State and in the Mohawk Valley. In the highlands the drainage was too free and vigorous. In the Champlain-Hudson Valley, lower levels, the sealevel waters distributed the glacial stream detritus, or it was buried under the deluge of sand contributed by the rivers since the ice disappeared. The very extensive sand plains on both sides of the Hudson River and Lake Champlain—for example, the Saratoga District—must be classed as marine deltas; but on the walls of the great valley above the marine plain Woodworth has noted ice-contact slopes of glacial outwash deposits. In the Susquehanna District Tarr found numerous plains of this class.

Extraglacial: valley trains.—South of the divide, where the drainage had free escape, some detrital filling of the valleys is common and occasionally abundant. The high-level floodplains along the valley sides and the elevated deltas of lateral tributaries testify to the glacial floods and their burden of detritus. The deposit by glacial flow is, of course, intermingled with and in places buried under land-stream detritus. The valley trains may be regarded as heading in outwash plains, and one might regard the glacial gravel deposits in the entire length of the valleys north of the terminal moraine as outwash. This view would restrict the true valley trains to the fillings of valleys beyond the terminal moraine or reach of the ice-sheet. In this latter view the valley-train drift would occur in New York only along the south side of Long Island and in the small area south of the Allegany River.

LAKES: GLACIAL

Occurrence.—The term "glacial" is used by the writer to include only lakes which existed by virtue of a glacier ice-barrier. The lakes and lakelets now existing and called "glacial" by some authors should be discriminated mostly as morainal or drift-barrier lakes.

The conditions necessary for a glacial lake are a valley or depression sloping toward and blocked by the ice-front. These conditions were fulfilled in New York on so large a scale, in area and time, that the State, it is confidently believed, held the largest number of glacial lakes and the most remarkable succession with varied outflow of any district in the world. The reason for this superiority is found in the peculiar topography of the western part of the State. In the great Ontario-Erie Basin we have a broad depression, with its lowest passes on the east and west, and with a deeply trenched southern slope, where lie the parallel valleys of the Finger lakes.

The only glacial lakes of which clear evidnce is preserved are those which lay against the receding front of the latest ice-sheet. But it should be clearly understood that every ice-sheet which transgressed the State blocked the waters both during its advance and its recession.

We do not know what portions of the Valley-Heads moraine, which now constitutes the divide and forms the south limits of the basin, were left there by pre-Wisconsin ice-sheets, but we may be quite sure that the lakes during the advance of even the last glacier were somewhat different in dimensions and relations from those of the ice recession which are the subject of our field study. We may also be sure that the earliest ice invasion found the series of parallel valleys with fairly mature and graded forms and open clear through to their heads, and the larger ones heading in Pennsylvania. Those earliest ice-impounded lakes must have been longer and deeper in the valleys than the lakes of later episodes, when the valleys had become more or less occupied by glacial and lake deposits. The lacustrine conditions of the episodes antedating the Laurentian ice-retreat are as yet a matter of interesting speculation. One further difference may be noted between the ice-advance and the ice-recession lakes. The primitive lakes of the ice-advance were the lowest in altitude and the most northerly in location and with the lowest outlets.

As the ice advanced and closed the outlets the waters were lifted to higher levels and pushed southward. The last lakes of the ice-advance being in the heads of the valleys were the smallest, the highest, the most detached and most southerly. The lakes of ice-front recession had precisely the opposite history.

Erosional work.—The lake features that are preserved for our study may be discriminated as erosional and constructional. The erosion phenomena are the wave-cut cliffs. The glacial lakes were commonly too ephemeral or too unsteady in their levels to produce conspicuous erosion features. However, the larger and longer-lived lakes, as Newberry, Warren, Dana, and specially Iroquois, have left many cliffs.

Constructional work—Beach ridges.—Embankments of sand and gravel, the bars and spits of wave and shore current construction are the complement of the erosion work, but are much more common and are frequently very prominent features. They have long been recognized by the people as the work of mysterious waters at high altitudes. For long stretches the beach ridges have been utilized for "ridge roads," while the level stretches of wave-base along the beaches have afforded graded paths for railroads and canals. The strongest ridges are those of Whittlesey and Warren in the Erie Basin and of Iroquois in the Ontario Basin.

Deltas.—Of the several shore phenomena deltas are the most useful in proving the former presence and determining the altitudes of the extinct lakes. The production and size of the delta deposits are not wholly conditioned by the size of the receiving water body, but by the volume of the stream detritus relative to the distributing work of the receiving waters. Hence deltas may be built in small lakes, and these hung-up mounds and terraces of gravel on the valley sides serve well to mark the shores of lakes that were too ephemeral or too small to produce either cliffs or bars. Naturally the deltas occur in the courses of land streams, and a vertical succession of bisected delta terraces commonly indicate the falling levels of the lake. Fine examples of these gravel terraces are found on the slopes of the Finger Lake valleys, and some of them are conspicuous features, like the terraces by Coy Glen, visible from the Cornell University campus.

Delta plains.—Genetically related to deltas are the plains of gravel, sand, or clay, which may be extended in area and indefinite in limits. Such plains usually represent wave-base, perhaps 20 feet or less beneath the water surface. When partially eroded the remnants present extended horizontal lines, excellent examples of which may be seen throughout the Mohawk Valley and about the Irondequoit Valley east of Rochester, clearly visible from the trains on the New York Central Railroad. Some of the larger valleys declining toward Lake Erie exhibit broad terraces at various levels. A fine display may be seen from the Pennsylvania Railroad from East Aurora up to Machias. Evidently such lake plains can occur only north of the divide. Some plains similar in appearance in the valley south of the divide fall into the categories of outwash plains or of river floodplains.

Scores of examples of detrital plains built in glacial waters by the land drainage might be cited. In the Erie Basin the great plain in the Cattaraugus Valley below Gowanda and that built by Silver and Walnut creeks between Forestville and Silver Creek villages may be mentioned. A very fine illustration is found on the Rochester sheet. The area between the Genesee River and Irondequoit Bay and between Lake Ontario and the Iroquois beach ("Ridge Road") is the submerged delta plain of the Genesee River in Lake Iroquois, now much dissected by present-day streams. The flat stretches about Irondequoit Bay bounded by the 400-foot contour are remnants of the silt plain, which in Iroquois time filled the whole breadth of the valley.

Sand plains built by the ice-border glacial drainage are also numerous. These include, for example, the plains on the west side of the Genesee Valley opposite Avon, the eroded area north and northwest of Geneva, the mesa-like plains in the Onondaga Valley at South Onondaga and northwest by Cedarvale, and the plain on which stands the business part of Syracuse.

The very extensive and conspicuous sand plains and terraces on both sides of the Champlain and Hudson valleys, including the great delta plain between Schenectady and Albany contributed by the Iromohawk River, were built in sealevel waters that occupied this depression during the time of the ice removal.

Clay plains.—Where the static waters were wide and deep, so as to permit full assorting of the detritus, more or less clay was spread over the bottom in the more quiet water. The best example is found in the Iroquois Lake Basin. In the St. Lawrence Valley east of Cape Vincent, Alexandria Bay, and Ogdensburg are extensive stretches of finely laminated and deep clays, the glacial origin of which is indicated by the abundance of lime concretions. The heavy clay deposits of the Hudson Valley belong in this class, but were deposited in sealevel waters.

Morainal lakes.—This class includes the hundreds of lakes and lakelets (so-called ponds) now in existence that are scattered over the State and most numerous in the Adirondacks. They owe their existence to the blockade of valleys or drainage courses by glacial drift. The term drift-barrier lakes would be the more accurate name. Great numbers of such lakes have already been obliterated, mostly changed into swamps by marl and peat accumulation or by detrital filling, and the existing lakes are doomed to similar ultimate extinction either by filling or draining.

The Finger Lakes probably owe their origin in part, at least in their upper levels, to drift barriers.

Cataract lakes.—The most singular and interesting lakes in the State lie in the courses of ancient ice-border rivers. These occupy the plunge basins of extinct cataracts. Niagara today illustrates the method in production of a basin or bowl by the excavating work of a large cataract. If Niagara River were to be diverted above the fall so as to extinguish the cataract, a rock basin holding a lake would probably be left in the amphitheater beneath what is now the "Horseshoe" Falls. South and east of Syracuse the predecessors of Niagara River plunged over cliffs of the Onondaga limestone in their eastward flow and produced several plunge basins that hold lakes, two of which outrival Niagara.

The Jamesville Lake, 4 miles southeast of Syracuse, is a circle of emerald green water about one-eighth mile in diameter and 60 feet deep, lying in a half-circle amphitheater with perpendicular rock walls 160 feet high. Two and one-half miles east of Jamesville Lake, across the Butternut Valley, is Blue Lake, resting in a cataract basin and rock amphitheater, equaling the Jamesville in dimensions, but not so symmetrical. White Lake, one-half mile north of Blue Lake, and Round and Green lakes, 9 miles east of Syracuse, have basins with low and sloping walls because the rocks are the soft Salina shales.

These lakes were formerly regarded as mysterious, and with their inclosing amphitheaters were the cause of much speculation. Their nature was first announced by G. K. Gilbert and the first geologic description in recognition of their true character was by Quereau.[10]

These cataract lakes are very remarkable features, and representing as they do an ancient drainage of the Great Lakes area, held at high levels by the glacier front, they have a scientific and educational value not yet appreciated.

Lakes of complex origin.—This title is intended to include Lake Ontario and the larger Finger lakes, as Cayuga and Seneca, the genesis of which is not entirely clear. The bottoms of these lakes are below sea-level, and we do not know what depth of drift lies yet deeper beneath the water. At Watkins a well boring penetrated 1,200 feet without reaching rock, which shows drift at a depth 600 feet lower than the deepest part of the lake and 750 feet beneath sealevel.

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[10] E. C. Quereau: Topography and history of Jamesville Lake. Bull. Geol. Soc. America, vol. 9, 1898, pp. 173-182.

See also illustrated article by Fairchild in the Twentieth Ann. Rept. New York State Geologist, 1900, pp. 126-129.

It seems probable that the valleys of the Finger lakes are blocked on the north, along the drumlin belt, by deep drift filling, which can be determined only by borings at close intervals. That these valleys were gouged out by ice erosion, even by any number of continental ice-sheets, seems to the writer extremely improbable. If they were so deepened, then the basin of Lake Ontario was probably also scooped by ice erosion. But if the Ontario Basin is a depressed river valley, then the valleys of the Finger lakes must be fairly graded to the bottom of Ontario and be of similar origin. If the Ontario and other basins were excavated by river work and weathering, then it must be admitted that there have been great changes in the height and attitude of the land in late geologic time; but such changes are quite certain. It appears probable that the valley-cutting occurred during a time of land elevation, and that the Laurentian and the Finger Lake basins are the complex product of land warping, land depression, and of glacial drift filling. Until the later Tertiary and Pleistocene diastrophic movements of the area, including New York, have been determined and the drift-buried valleys mapped by borings, the deep lake basins may remain the subject of speculation and dispute.

GLACIAL LAKE SUCCESSION

The story of the succession of the glacial waters that laved the receding front of the Laurentian glacier is a dramatic episode in the geologic history. Beginning in small pondings of water in the heads of the valleys along the north side of the morainic divide, the lakes were enlarged as the ice-barrier receded, and were captured, drained, blended, or otherwise affected by changes in outlets. The romantic story can not be satisfactorily told in words alone, but requires cartographic representation, and a series of maps have been constructed to show the better known and more striking changes in the ice recession and the lake succession.

The control of the glacial waters depended on the altitude of the lowest passes affording immediate outflow, along with the relation of these passes to some ultimate escape. The waters of the Laurentian Basin outflow today by the St. Lawrence (246 feet). With that escape blocked the lowest pass is at Rome (460 feet for the water surface) to the Mohawk-Hudson, and which for many thousands of years was the point of escape of the waters while the ice-body lay over the St. Lawrence Valley. The next higher pass is at Chicago, which was occupied by the glacial outflow for a very long time, but to reach this ultimate escape the Ontario-Erie-Huron waters were compelled to cross Michigan by the valley of Grand River.

The lowest pass leading southward in New York is at Horseheads, the head of the Seneca Valley, leading to the Chemung-Susquehanna, with altitude of 900 feet. These three outlets—Horseheads, Grand Valley (Michigan) and Rome—were the channels of ultimate escape for the waters of western and central New York until the ice was removed from over Covey Gulf, north of the Adirondacks. In immediate control of the waters of central New York, the Seneca-Cayuga depression and the Genesee Basin, there were two localities, the salient or highland on the Batavia meridian and the highland in the Syracuse District. The earliest glacial waters in New York were held in the Genesee Valley, and this continued for a long time as a distinct basin, with several successive outlets.

When we consider the glacial lakes and drainage in chronologic order we find that the earlier waters were confined in two separate basins, the Genesee and the Seneca-Cayuga: that for a brief time Lake Newberry (the Horseheads outlet) probably occupied the Genesee Valley, and then for a long time the control was alternately west on the Batavia meridian or east on the Syracuse District. Then, when the ice-front weakened on the Batavia salient, the westward control was across Michigan (Lake Warren level). All the later flow subsequent to Lake Warren was eastward to the Hudson until the northward flow through Covey Gulf to the Champlain Valley and the Hudson.

The most extended series of glacial lakes was in the Genesee Valley. This long valley, the surviving example of the pre-Pleistocene northward drainage, heads in Pennsylvania, at the terminal moraine, with altitude on the cols over 2,200 feet, and extends across the State to near Rochester, where it blends into the Ontario lowland at about 600 feet altitude. The fall of 1,600 feet in a right-line distance of 80 miles gave opportunity for many successively lower outlets and water planes as the ice released passes on the east or west borders of the basin. Probably the glacial lake history of the Genesee Valley is more complicated than is now known, but no less than eighteen distinct outlets, with correlating lake levels, have been recognized. Later the drainage was directly into the sea (Gilbert Gulf), and finally into Lake Ontario. In this varied outflow the Genesee glacial waters were contributed to several far-separated river systems. Named in order of time, these are: (1) Pine Creek-Susquehanna; (2) Allegany-Ohio-Mississippi; (3) Canisteo-Chemung-Susquehanna; (4) Erie Basin (lakes Whittlesey or Warren)-Michigan Basin (Lake Chicago)-Mississippi; (5) Seneca Valley (Lake Newberry)-

Susquehanna; (6) Mohawk-Hudson; (7) Champlain-Hudson; (8) ocean-level waters direct; (9) Lake Ontario-St. Lawrence. Some of these systems received the Genesee Valley overflow more than once, or by different immediate outflow, making the twenty stages in the drainage history as now understood. It would seem unlikely that any other valley in the world can approach the Genesee in the complexity of its drainage history.

The series of sixteen maps depict the waning Laurentian ice-sheet with the glacial and marine waters that lay against its receding border. The local lakes in the side valleys of the Hudson depression and about the Adirondack highland are not indicated, and the ice border is more or less generalized. The latter is located definitely along the lines of the ice-border drainage.

The chart (page 158) shows the time relationship of the waters in the several basins of the State. The vertical spacing is only suggestive of the succession of the waters and their geographic relations and has little significance as to the duration of the episodes.

MARINE WATERS

During the waning of the latest ice-sheet the Hudson-Champlain Valley and the St. Lawrence and Ontario basins were beneath the level of the ocean. As the ice-front receded northward the sealevel waters followed up the Hudson Valley, finally reaching the Champlain Basin and eventually uniting with the oceanic waters of the St. Lawrence Gulf. The Hudson Inlet thus became the Hudson-Champlain Inlet, and finally the Hudson-Champlain Strait, connecting New York Bay with the Champlain Sea. When the ice-front backed away from the Covey Hill promontory the glacial waters of the Ontario Basin, the Second Iroquois, fell to and became confluent with the sealevel waters. The highest plane of the sealevel waters in the Ontario Basin is relatively weak and has not been fully determined, but an inferior level of long persistence, showing heavy bar construction, has been mapped and named Gilbert Gulf. This stage, which includes the series of strong bars at Covey Hill post-office, is depicted in map number 16.

On the parallel of New York city it appears that the land at the time of the ice recession was at, or perhaps somewhat above, sealevel. Northward the land was increasingly below sealevel. The upraised and tilted water plane, which indicates the amount of Pleistocene submergence or of post-Pleistocene uplift, rises steadily from zero or present sealevel in the district of New York city to over 700 feet on the Canadian boundary.

Glacial Lakes of New York State

DRAINAGE PROVINCES						
ERIE	GENESEE	SENECA	MOHAWK	BLACK	ST. LAWRENCE	HUDSON-CHAMPLAIN
Ice	1. Three Primary	*Ice*	*Ice*	*Ice*	*Ice*	
	2. Pennsylvania					
	3. Wellsville					
	4. Belfast-Fillmore					
	5. Portage-Nunda	Primary (several)				
Whittlesey	6. Dansville					*Hudson marine inlet*
	7. Mt. Morris-Geneseo	Newberry	Herkimer Schoharie Amsterdam			
	8. Newberry					
Warren	9. Hall	Hall		Forestport Port Leyden Glenfield		
	10. Vanuxem	Vanuxem				
	11. Avon	Montezuma				
	12. Second Vanuxem	Second Vanuxem	*Glacio-Mohawk River*			*Hudson-Champlain marine inlet*
	13. Warren	Warren				
Dana	14. Dana	Dana				
Lake Erie	15. (?)	Iroquois	*Iromohawk River*			
	16. Dawson			Iroquois		
	17. Iroquois				Iroquois	
	18. Second Iroquois	Second Iroquois	*Mohawk River*	*Black River*	Second Iroquois	
	19. *Gilbert Gulf (marine)*	*Gilbert Gulf (marine)*			*Gilbert Gulf (marine)*	*Hudson-Champlain Strait*
	20. *Ontario*	*Ontario*			*St. Lawrence River*	

The supposed absence of marine fossils in the Hudson Valley is doubtless due to the freshening of the waters by the copious glacial and land drainage. Until the episode of the Second Iroquois the flood of glacial waters of the St. Lawrence Basin was poured into the Hudson Inlet at Schenectady. During the Second Iroquois the glacial flood was merely shifted to the north, and during all the long life of the Hudson-Champlain Inlet all the fresh waters were forced south. However, marine fossils are abundant in the Champlain Valley and are found at altitudes the planes of which carry over the Fort Edward Divide into the Hudson portion of the great valley.

The detrital deposits formed in the marine waters are large in volume and area. Up the Hudson as far as Catskill the terraces of clay and sand are very conspicuous and afford the materials for brick manufacture on an immense scale. North of Catskill, in the widening valley, the summit sand plains lie back from the river, though lower terraces may yet be seen. While much of the deeper deposits and those in the middle of the valley or beneath the present waters are of glacial origin, the heavy visible deposits are chiefly the deltas of tributary land streams, the greatest being that of the Iromohawk at Schenectady-Albany.

From Troy to Glens Falls the borders of the lower valley are buried in a deluge of sand, sloping down in terraces toward the axis of the valley. Saratoga lies in the midst of a vast area of detrital marine accumulations. The slow lifting of the valley out of the waters gave the latter an excellent chance to produce level stretches and conspicuous terraces, the latter being more prominent as the steeper slopes approach the middle of the valley. The Champlain portion of the great valley also holds vast sand plains, especially on the larger rivers, as the Ausable, Saranac, and Big Chazy.

Epeirogenic Movement: Diastrophism

The great changes in altitude of the surface of the State, both before and since the glacial occupation, has already been noted. The relation of the land movement to the burden of the ice-cap should be briefly discussed. If the earth's crust is sensitive to long-continued pressures, then the thickness and weight of the ice-body become an important matter.

Again, our lack of knowledge of the duration and diastrophic effects of the pre-Wisconsin ice-caps limits our discussion to the effects of the Laurentian ice-body.

At its maximum the thickness of the ice-cap over the Adirondacks and the Champlain Valley was probably not less than 10,000 feet. This is equal in weight to over 3,000 feet of rock. Southward the ice decreased in thickness and weight to zero in the region of New York Bay. The amount of postglacial uplift increases from zero in the district of New York Bay to over 700 feet on the north boundary of the State. The correspondence between the thickness of the ice-cap and the amount of postglacial uplift of the land is very striking and significant. All about the Laurentian Basin the tilted shores of the extinct glacial lakes afford us evidence of the differential uplift of the glaciated territory.

The average northward uplift or tilt of the marine plane in the Hudson and Champlain Valley appears to be about two and one-fourth feet per mile, but some higher and as yet uncorrelated shore features in the Champlain Valley suggest a deeper submergence there and a larger rate of uplift. It seems quite certain that the increase of the gradient northward that is apparent west of the Adirondacks must also occur on the east of that mountain mass. The differential uplift between the Iroquois plane at Rome (460 feet) and at Covey Gulf, on the Canadian boundary (1,025 ? feet), is about 665 in a distance of 149 miles in a direction 33 degrees east of north, giving a slant of 3.8 feet per mile. The grade from Richland to East Watertown is toward 6 feet per mile.

In east and west direction there is small deformation. The Iroquois plane at Hamilton, Ontario, is given as 363 feet. At Rome it is 460 feet, which makes an eastward uplift of 100 feet in 225 miles, 0.4 feet per mile.

The steadiness or uniformity of the tilted marine plane in the Hudson and southern part of the Champlain valleys is somewhat surprising. It does not seem probable that all land uplifting was deferred until the ice was removed from a stretch of 200 miles, and that the rise and tilting was that of a rigid mass. It would seem more likely that as the weight of the ice-sheet was slowly removed it was followed by a progressive wave of land uplift. However, the final result of an epeirogenic wavelike uplift might be a fairly uniform plane, simulating that produced by tilting of a rigid surface.

Postglacial Erosion

Land erosion since the ice-sheet disappeared is exhibited in wave-cutting by the lakes and canyon-cutting by diverted streams. In postglacial ravines New York State excels. We may recall Niagara, the three ravines in the course of the Genesee, the Ausable chasm, and Watkins Glen; but there are great numbers of glens or steep-walled rock gorges throughout the State which are quite as interesting and instructive as these, even if smaller and unadvertised.

When applied to the effects of erosion in New York, the term "postglacial" needs explanation, for much canyon-cutting was effected while the ice-sheet still lingered on territory of the State. For example, the Portage ravine of the Genesee began cutting while the ice-front was not far away on the north. The Mount Morris ravine, the "High Banks," was in the making while the ice covered Rochester, and the upper (south) section of the Rochester Canyon was largely cut while Lake Iroquois waters prevented the excavation of the lower part of the gorge. Certainly a large part of the erosional work in central and western New York and the Hudson Valley occurred while the glacier still covered the northern lowlands of the State, including the Champlain Valley.

Glacial Time

The first question commonly asked by the non-geologist is, "How long ago?" We have to admit ignorance of any precise measure of geologic time. Geologists have learned to think in millions of years, and they are not greatly concerned with the precise duration of so short a period as the glacial or postglacial episode. However, precise knowledge is desirable and a yardstick of geologic time must be sought. All attempts to use the present rate of canyon-cutting or cataract recession as an index of time have failed, and no data yet discovered have much value.

The history of the ice-front recession, with its long succession of lakes and well developed river channels, compels the extension of our estimates of the length of glacial time, and all studies in glacial geology have the same result.

If we take 10,000 years as a moderate estimate of the life of Lake Ontario, then we must add an equal, and perhaps much greater, time for the lifting of the basin out of the marine waters. Then we must allow at least another 10,000 years for the duration of Lake Iroquois, and the 30,000 years carries us back only to the time when the ice-sheet was removed from the western part of the State. This appears to be but a minor portion of the time covered by the waning of the glacier, judging from the maps and the known history preceding the initiation of Lake Iroquois.

If we assume 75,000 years as the time in the waning of the ice-sheet, then we seem compelled to add an equal time for the invasion of the ice, with some time in addition for the pause at the terminal moraine. Most glacialists will probably agree that 150,000 years for the length of the latest or Wisconsin ice epoch is a fair estimate, and back of this we have the earlier and much longer Glacial and inter-Glacial epochs. The estimates of those best qualified to judge of the length of Pleistocene time are from 500,000 to 1,500,000 years.

WORK OF THE STATE SURVEY

The Pleistocene phenomena of the State have been the subject of casual observation and publication for over half a century and a bibliography would be too large to present here; but the Glacial and Pleistocene is the youngest member of the geologic branches of study, and only in recent years has the New York State Museum financed the glacial study as a distinct line of field work and publication. This assistance, however, has been generous and effective, as the numerous papers and handsome maps published since 1900, and specially since 1905, will bear witness. The only elaborate and expensive maps and text published under other auspices than the State Museum is the U. S. Geological Survey Folio 169, already cited above. A description of the Moravia quadrangle by Carney was published in 1909 by Denison University, with a sketch map in black and white.

The more important Pleistocene publications of the State Museum are Bulletins 48, 83, 84, by Woodworth; 154, by Stoller, and 106, 111, 127, 145 (in part), and 160, by Fairchild. Earlier papers by the writer are contained in the Twentieth Annual Report of the State Geologist, 1902; Twenty-first Report, 1903, and the Twenty-second Report, 1904. Previous papers by the writer on the Pleistocene features of the State were published in the Bulletin of this Society, beginning in 1895, and in other scientific journals.

For effective future work it is desirable that some scheme or far-sighted plan should bring all the glacial studies of the State into harmonious cooperation for the large result, and also that a cartographic scheme should be adopted that will secure maps as uniform in convention and color as possible.

Two important subjects requiring systematic study are the moraines and the drift-buried valleys. The State should undertake the mapping of the buried valleys. It should employ a well-boring outfit to secure data for accurate profiles of the hard-rock surfaces beneath the drift north of the Finger lakes and wherever the preglacial valleys of scientific interest are obscured. This would be a unique and popular work for the State Museum. The expense of such exploration would not be large, while the scientific and educational value would be great.

Another duty of the State is the preservation intact of the Jamesville and Blue Lakes cataract features. These splendid evidences of an ancient glacial drainage antedating Niagara and corresponding in function should be made State property and preserved for the people. They are scenic features of as much beauty and of much more educational value than Watkins Glen and some other State parks.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 24, PP. 163-186 JUNE 6, 1913

REPORT OF THE COMMITTEE ON THE NOMENCLATURE OF FAULTS[1]

BY HARRY FIELDING REID, *Chairman;* WILLIAM MORRIS DAVIS, ANDREW C. LAWSON, F. L. RANSOME, *Committee*

(Presented before the Society December 28, 1912)

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INTRODUCTION

The great inconsistency in the use of terms relating to faults, and especially the lack of uniformity when dealing with faults in which there is a component of displacement parallel with the fault strike,[2] led to the appointment by the Council of the Geological Society of America at the Baltimore meeting, December, 1908, of a Committee on the Nomenclature of Faults. This Committee was charged with recommending a proper nomenclature. A preliminary report was made at the Washington meeting, December 30, 1911, and was printed as a special brochure by order of the Council, under the title "Proposed Nomenclature of Faults." Copies were sent to all Fellows of the Society and a few other geologists with the request that it be freely criticised. The Committee received a number of letters containing apt criticisms and making useful suggestions. As a result of these letters and the discussion at the New Haven meeting, December 28, 1912, some important changes have been made in the preliminary report. The Society ordered that the revised report be published in the Bulletin, in order that Fellows might give the nomenclature a working test before any official action should be taken by the Society.

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[1] Manuscript received by the Secretary of the Society March 20, 1913.

[2] This was clearly shown by Mr. Ransome and by the discussion which followed his paper, "Economic Geology," vol. i, 1906, pp. 777-789; vol. ii, 1907, *passim*.

In carrying out its instructions the Committee has been guided by the following principles:

1. To introduce as few technical words as possible; it is unnecessary to have a technical word to denote the component of the displacement in every direction in which it may be measured.

2. To use words which suggest the technical meanings to be attached to them.

3. To make no changes in words which have a recognized meaning, and to follow the best usage where a word is used in different senses. We are not dealing with a new subject, but are attempting to standardize the words now in use and to adapt them to a broader conception of fault movements. We believe that no system of nomenclature will be accepted which breaks with the best present usage. This makes it impossible to adopt a system which is perfectly logical.

4. To make the classification geometric and descriptive, not genetic, in order that a fault may be described so far as it may have been observed without any inferences as to the forces which produced it. For instance, a so-called "thrust fault" may sometimes be formed without any compression, and a "tension fault" without any tension; the terms "thrust" and "gravity" faults have been frequently used. All these terms are dynamic and not geometric; they should only be used after the forces which produced the fault are understood.

The discussion of the nomenclature of faults in Economic Geology, which bore especially on the nomenclature of fault movements, showed a wide divergence of view, some writers desiring to use descriptive terms only, and some insisting that no proper classification could be made without considering the forces producing the faults. The Committee takes the former view, thinking it important to be able to describe as much as may have been learned about a fault in simple, definite language before the whole movement and the force which has caused it are known; in many cases these will never be known. A dynamic system of classification and nomenclature will be in order when the dynamics of faults is better understood.

Spurr[3] and Tolman[4] have proposed systems of nomenclature for fault movements which are feasible; the latter's system is especially logical and full. The objections to both are that they break with the best usage, and that the terms do not suggest the component of the displacement denoted by them. These are serious objections. A strong effort has been made to render the system here proposed not open to these objections.

De Margerie and Heim[5] have collected the terms used to describe faults up to 1888. But little is said of strike-slip faults and they do not suggest a consistent nomenclature, but merely collate the terms used.

Geological text-books give but few terms descriptive of fault movements. Those of Scott,[6] A. Geikie,[7] and J. Geikie[8] are the fullest.

Our present nomenclature has developed largely in relation to movements up or down the fault plane. It becomes inadequate when movements occur parallel with the fault strike, movements now recognized as very general. It is important, therefore, to extend the meaning of the old terms and to introduce some new ones, but in a way not to disturb the older usage nor to introduce any confusion by the new applications.

In what follows many definitions are given for the sake of continuity which might otherwise be omitted.

General Terms

A fault, in its simplest form, is a fracture in the rock of the earth's crust, accompanied by a displacement of one side with respect to the other in a direction parallel with the fracture. The fracture is usually not an open crack, and an open crack would not be a fault unless one of the sides had moved parallel with the crack relatively to the other. A monoclinal displacement, however steep, is not a fault; but it might, by tearing, pass into a fault. Faults rarely consist of a single clean-cut fracture; they are usually made up of a number of fractures, as noted below.

---

[3] Geology applied to mining. New York, 1904.

[4] Economic Geology, vol. ii, pp. 506-511. Graphical solution of fault problems. San Francisco and London, 1911.

[5] Les Dislocations de l'écorce terrestre. Zurich, 1888.

[6] An Introduction to Geology, 2d ed., 1907.

[7] Text-book of Geology, 4th ed., 1903.

[8] Structural and Field Geology, 1905.

As we pass from one part of a fault to another, we find that certain characteristics vary. For instance, the two walls of the fault may be, in some places, in contact; in others separated; one wall may be elevated relatively to the other in one part of the fault's course and depressed in another part, etcetera. Definitions descriptive of characteristics which vary locally must, therefore, be considered as referring to the parts of the fault to which they are applied and not necessarily to the fault as a whole.

A closed fault is one in which the two walls of a fault are in contact.

An open fault is one in which the two walls of a fault are separated. The same fault may be closed in one part, open in another.

The fault space is the space between the walls of an open fault.

A fault surface is the surface of fracture; it is rarely plane, but where it is without notable curvature over any area it may be called a *fault plane* for that area. The word "surface" should not be restricted to its accurate mathematical meaning. The shear zone, if sufficiently thin, would in general be referred to as the fault surface; but if it is wide and has definite boundaries, these may constitute two fault surfaces.

A fault line is the intersection of a fault surface with the earth's surface. The same word might also be used to denote the intersection of the fault surface with any artificial surface of reference, such as the floor of a tunnel, mine level, etcetera.

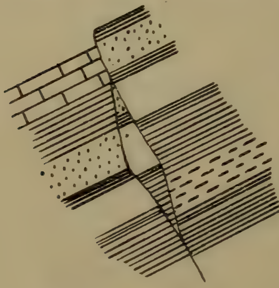
FIGURE 1.—*A Horse.*

The shear zone: Where a fault is made up of slips on closely spaced surfaces, with more or less deformation of the intervening rock, the portion of the earth's crust containing these minor faults is called the shear zone. This name would also apply to the brecciated zone which characterizes some faults.

Multiple fault: This term may be used to designate a group of parallel faults fairly near together, the intervening rock not being distorted. The term shear zone would hardly be applicable to this case.

An auxiliary fault is a minor fault ending against the main fault. It is often the boundary of a dropped wedge.

The outcrop of the fault is the area along which the shear zone comes to the earth's surface. In the case of a sharply defined fault the outcrop and the fault line become synonymous.

The fault breccia is the breccia which is frequently found in the shear zone, more especially in the case of thrust faults.

Gouge is the pulverized rock, generally claylike when moist, which is often found between the walls of a fault.

A horse is a mass of rock broken from one wall and caught between the walls of the fault. (See figure 1.)

The fault strike is the direction of the intersection of the fault surface, or the shear zone, with a horizontal plane.

The fault dip is the inclination of the fault surface, or shear zone, measured downward from a horizontal plane. It is never greater than 90 degrees.

The hade is the inclination of the fault surface, or shear zone, measured from the vertical; it is the complement of the dip. A fault is said to hade to the side toward which it dips.

The hanging wall is the upper wall of the fault.

The foot wall is the lower wall of the fault.

General Classes of local Movements on Faults

Movements on faults may be classified, according to the character of the local displacement, into translatory and rotatory movements.

Translatory movements are those in which all straight lines on opposite sides of the fault, and outside the dislocated zone, which were parallel before the displacement, are parallel afterward. If at a later date, or even at the time of the displacement, the whole region were tilted, the movement would still be considered a translatory movement, so far as the fault is concerned.

Rotatory movements are those in which some straight lines on opposite sides of the fault and outside the dislocated zone, parallel before the displacements, are no longer parallel afterward—that is, where one side of the part of the fault under consideration has suffered a rotation relative to the other side.

No faults of any magnitude exhibit merely translatory movements over their whole lengths. Faults die out and the displacement is not uniform along them, so that there is necessarily some slight rotation, varying in amount in different parts of the fault's course. Probably the greatest number of faults, certainly all large faults, are of this character. The variations in rotation and translation are permitted by slight plastic deformations. If, however, we confine our attention to a *small part* of the fault, we may describe the displacement there as though the rock were rigid; and if the rotation is very small, as if a translatory displacement had occurred, and for conciseness we may use the terms *translatory fault*, or *rotatory fault*, to describe the part under consideration. It sometimes happens that the strikes on opposite sides of a fault are different; this suggests a rotation, but it may be due to a local variation of strike or to an unconformity.

Our determinations are almost always relative, and hence we can rarely tell which side of the fault has moved; therefore the expressions "upthrow" and "downthrow," which are used according to the side from which the fault is viewed, are objectionable, as they suggest that a particular side of the fault has actually been moved. They are in too general use to be abandoned, but it should be definitely understood that they refer merely to a relative and not to an absolute displacement.

It is desirable to emphasize the fact that the definitions which follow refer, with a few exceptions, to the part of the fault under consideration and not necessarily to other parts nor to the fault as a whole.

We give the word "displacement" no technical meaning, but reserve it for general use; it may be applied to a relative movement of the two sides of the fault, measured in any direction, when that direction is specified, or to the change in position of a bed, etcetera, caused by the fault movement. The word "dislocation" will also be most useful in a general sense.

TRANSLATORY MOVEMENTS

GENERAL DISCUSSION OF TERMS

There are two ways of defining the displacement due to a fault; we may define the apparent relative displacement of a bed by naming the distance between its two disrupted branches measured in any chosen direction, such as the vertical distance between the branches, measured in a shaft, or the perpendicular distance between the lines of intersection of the two branches with the fault plane; or we may define the actual relative displacement of the two sides and its components, in important directions. The apparent displacements are those usually measured directly; the actual displacement must be worked out for a complete understanding of the fault.

It is necessary to have different words to indicate displacements measured in these two ways. For this purpose we have adopted the following technical words, qualifying words being added to indicate the component of the displacement referred to:[9]

Slip, which indicates the relative displacement of *formerly adjacent points* on opposite sides of the fault, *measured in the fault surface.* The qualifying words relate to the strike and dip of the fault surface.

Shift, which indicates the relative displacement of *regions* on opposite sides of the fault and *outside the dislocated zone.* The qualifying words relate to the strike and dip of the fault surface, with the exception of the vertical shift, and this expression is self-explanatory. When the fault is a fairly clean-cut fracture and there is no bending of the strata, the slip and shift are identical.

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[9] The exact definitions of these words will be given further on.

Separation, which indicates the distance between the *surfaces* of the two parts of a disrupted bed, vein, or of any recognizable surface, measured in any indicated direction. The separations will usually be measured, the slip and shift calculated.

Throw and heave, which refer to the displacement of the *edge* of a disrupted bed.

By keeping in mind the general meaning of these words, all confusion in the uses of the proposed nomenclature can be avoided.

There is no generally accepted word in present use to denote the slip. Willis and Tolman use "displacement;" Spurr uses "throw." We have reserved displacement for general use, and the word "throw" is at present used in quite a different sense. Becker used "slip measured on the dip of the fissure." [10] The generalization of this word to comprehend any movement in the fault surface is natural, and the word suggests its own meaning. The word "shift" also suggests the meaning attached to it; there is no distinctive word now in use to describe the shift.

In mines, where the fault surface itself is visible, the slip will generally be determined; it is of paramount importance in mining. In field surveys, where the fault is studied by the dislocation of the outcrop of strata, or dikes, often at a considerable distance from the fault, the shift is determined. The shift is of greater importance in the larger problems of geology than the slip. The distinction between the slip and the shift is important; it has not heretofore been recognized in the nomenclature of faults.

The separations are very useful terms. The perpendicular or stratigraphic separation is of the greatest importance. It is frequently the only important displacement determined, and in strike faults all the displacements in a vertical plane at right angles to the fault strike—that is, all the displacements which have heretofore been given the most attention—can be expressed in terms of it. The offset is often the most important surface measurement made.

FAULTS IN STRATIFIED ROCKS

Among stratified rocks the character of the displacement of the strata due to a fault is so much influenced by the relation of the strike of the fault to the strike of the strata that special subclasses are generally recognized.

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[10] Geology of the Comstock Lode, p. 176. Monographs of the U. S. Geological Survey, vol. III.

A strike fault is one whose strike is parallel to the strike of the strata.

A bedding fault is a special form of strike fault whose surface is parallel with the bedding of the stratified rocks.

A dip fault is one whose strike is approximately at right angles to the strike of the strata.

An oblique fault is one whose strike is oblique to the strike of the strata.

These terms are, of course, not directly applicable in regions of unstratified rocks; but they might be used in such regions with respect to the strike of a system of parallel dikes if this were distinctly stated in the description of the faults.

Similarly with regard to the general structure of the region:

A longitudinal fault is one whose strike is parallel with the general structure.

A transverse fault is one whose strike is transverse to the general structure.[11]

SLIP

The word "slip" indicates the displacement as measured *on the fault surface;* the qualifying words refer to the strike and dip of the fault.

The slip, or *net slip,* is the distance, measured on the fault surface, between two formerly adjacent points situated, respectively, on opposite walls of the fault. It would be represented by a straight line in the fault surface connecting these two points after the displacement; *ab* in figures 2 and 3.[12]

The strike-slip is the component of the slip parallel with the fault strike, or the projection of the net slip on a horizontal line in the fault surface; *ac* in figures 2 and 3.[13]

The dip-slip is the component of the slip parallel with the fault dip, or the projection of the slip on a line in the fault surface perpendicular to the fault strike; *bc* in figures 2 and 3.[14] The strike-slip and dip-slip are rectangular components of the net slip.

The trace-slip is the component of the slip parallel with the trace of a bed, vein, or other surface on the fault plane.

The perpendicular slip is the component of the slip at right angles to the trace of a bed, vein, or other surface on the fault plane. It equals

---

[11] See the word "flaw" further on.

[12] Spurr and Tolman call this the "total displacement."

[13] Tolman calls this the "horizontal displacement."

[14] Tolman calls it the "normal displacement."

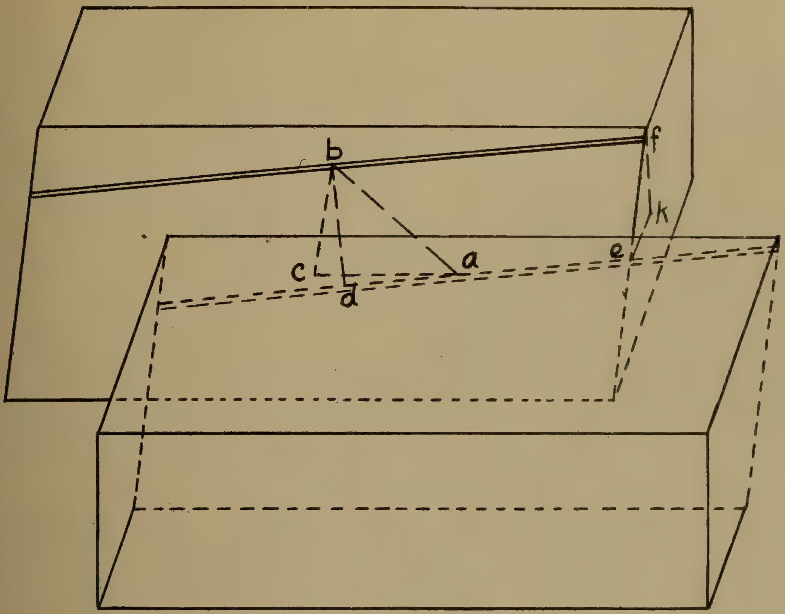

FIGURE 2.—*The Slip, Throw, and Heave*

The upper and lower surfaces of the block are horizontal; the end faces are vertical and at right angles to the fault strike. *a, b, c,* and *d* lie in the fault-plane; *e, f,* and *k,* in the end face. Let the point originally adjacent to *a* move to *b*; then

ab = slip or net slip
cb = dip-slip
ac = strike-slip
bd = perpendicular slip
ad = trace-slip
fk = throw
ek = heave

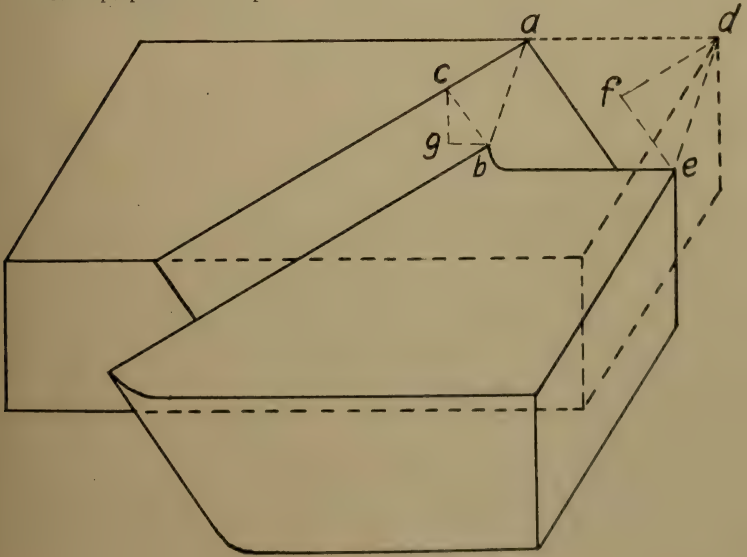

FIGURE 3.—*The Slip and Shift*

the perpendicular, or shortest, distance, measured on the fault plane, between the two parts of a dislocated bed, vein, or other surface; *bd* in figure 2.[15] The trace-slip and the perpendicular slip are rectangular components of the net slip.

SHIFT

It frequently happens that a fault has not a single surface of shear, but consists of a series of small slips on closely spaced surfaces, and in some faults the strata in the neighborhood of the fault surface are bent, so that the relative displacements of the rock masses on opposite sides of the fault may be quite different from the slip and not even parallel with it. The word "shift" is used to denote the relative displacements of the rock masses situated outside the zone of dislocation; the qualifying words relate to the strike and dip of the fault with one exception, in which the meaning is clear.

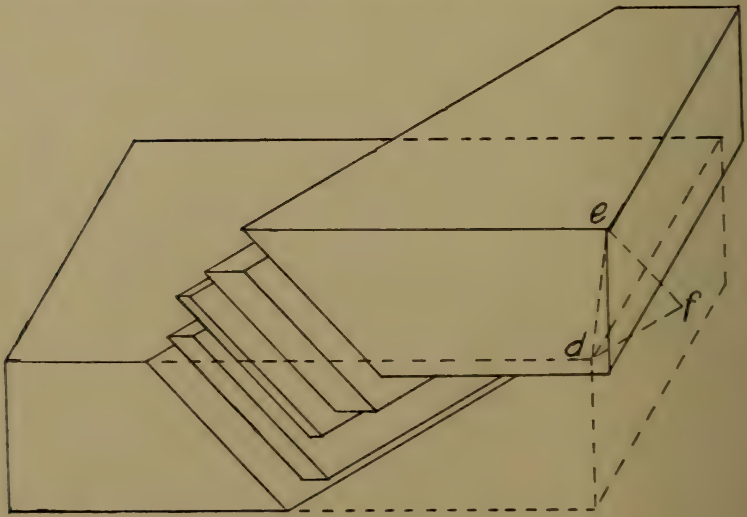

FIGURE 4.—*The Shift*

The shift, or net shift, denotes the maximum relative displacement of points on opposite sides of the fault and far enough from it to be outside the dislocated zone; *de* in figures 3 and 4, where *d* is the position of a selected point before and *e* after the faulting.

The strike-shift is the component of the shift parallel with the fault-strike; *df* in figures 3 and 4.

The dip-shift is the component of the shift parallel with the fault dip;

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[15] Spurr calls this the "lateral separation."

fe in figures 3 and 4. (The triangle *def* is parallel with the fault surface in figure 4.)[16]

The bending of the strata near the fault may be so great that the direction of the shift is no longer even nearly parallel with the fault surface; it is better, then, to use the three following components of the shift:

The strike-shift denotes the horizontal component of the shift parallel with the fault strike, as already defined.

The normal shift denotes the horizontal component of the shift at right angles to the fault strike. It equals the horizontal shortening or lengthening of the earth's surface at right angles to the fault strike, due to the fault.

The vertical shift denotes the vertical component of the shift. These components of the shift may evidently be used when the shift is parallel with the general trend of the fault surface.

SEPARATION

The separation of a bed, vein, or of any recognizable surface, is the distance between the *corresponding surface* of the two parts of the disrupted bed, etcetera, measured in any indicated direction.[17] The distance must be measured between the *corresponding surfaces* on the two sides of the faults—for instance, between the upper surfaces of the two parts of the disrupted bed or between their lower surfaces—but not between the upper surface of one part and the lower surface of the other. Moreover, the surfaces considered must be parallel with the general extension of the bed, vein, etcetera, such as the upper or lower surface of a bed or the walls of a dike.

The vertical separation is the separation measured along a vertical line.

The horizontal separation is the separation measured in any indicated horizontal direction.

The normal horizontal separation of a bed or other surface is its horizontal separation measured at right angles to the strike of the bed, etcetera. It is frequently determined from the outcrops of the bed at the surface of the ground; it is then usually called the *offset* of the bed. If figures 5 and 6 represent the ground plan of oblique faults on a level surface, *ab,* and not *ac,* would be the offset of the bed. *ac* would be the horizontal separation along the fault strike. *cb,* in the same figures, might be called the *gap* and *overlap* of the bed, respectively; they are measured parallel with the strike of the bed.

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[16] The dip-shift and strike-shift are not accurately shown in figure 3, because the net shift, *de*, is not parallel with the fault plane, and the lines *de*, *df*, and *fe* would not lie in one plane. But the definitions are clear and the figure illustrates them fairly well.

[17] The word "separation" is adopted from Spurr, and is somewhat generalized.

The perpendicular separation is the distance between the planes of the two parts of a dislocated bed or other surface measured at right angles to these planes.

The term *stratigraphic separation* may be used to denote the perpendicular separation of the strata. The expression "stratigraphical throw" was suggested by De Margerie and Heim[18] to represent what we have called the stratigraphic separation. It was adopted by Willis[19] and has found its way into some text-books. It has no relation to the "throw," as defined below, and it seems unwise to use the same word to represent displacements of quite different kinds. (For illustrations of the separations see figures 15, 16, and 17.)

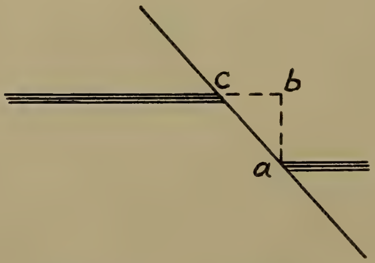

FIGURE 5.—*Plan of an oblique Fault.*

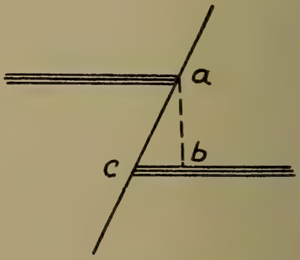

FIGURE 6.—*Plan of an oblique Fault.*

It is extremely important clearly to distinguish between the slip and shift and the separation. The first two refer to the actual relative displacement of the two sides of the fault, the last to the relative displacement of the surfaces of the two branches of a dislocated bed, etcetera.

Movements of one side or of both sides of the fault parallel with the plane of a bed would not alter the separation of the bed, but would materially alter the slip and shift.

The measures which will be most commonly made are the offset at the surface, and the vertical and horizontal separations in shafts and drifts, respectively. In order to determine the slip or shift, it is necessary to know the original and displaced positions of a point; this is not always possible, and the slip and shift have rarely been determined with accuracy. If striæ on the fault surface should give the direction of the slip, the displacement of a bed in that direction would be the slip. Other methods must be used with other data.[20]

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[18] Loc. cit., p. 18.

[19] Mechanics of Appalachian Structure. Thirteenth Ann. Rept. U. S. Geological Survey, 1891-1892, pt. ii, p. 224. He reduces the first word to "stratigraphic."

THROW AND HEAVE

The generalization of "throw" and "heave" presents peculiar difficulties. They apparently first came into use in the coal fields of Great Britain, where in general the strata are nearly horizontal or the faults are strike faults. If a fault were encountered when a coal seam was being worked, it would be important to know how far a drift should be run horizontally and how far a shaft should be opened vertically to reach the other part of the disrupted seam. The necessity of expressing these distances succinctly seems to have given rise to the two terms; the "heave" to represent the horizontal distance, the "throw" to represent the vertical distance, between the two ends of the disrupted seam. The choice of the words themselves evidently depended on the fact that the distances to be expressed were exactly equal to the relative horizontal and vertical displacements of the two sides of the fault, and the words were used indifferently to express the distances mentioned and the displacements. When, however, we have to do with oblique faults, a glance at figures 13 and 14 will show that the vertical distance between the ends of the disrupted bed will vary with the horizontal direction between the points to be used for its determination, and that, in the case of oblique-slip faults the stratum on the downthrow side of the fault may be above that on the upthrow side, and *vice versa.* Therefore the two uses of the word "throw" become completely incompatible, and it becomes necessary to limit the word to one of the displacements mentioned. It seems impossible to separate the word from its relation to the strata and apply it to the relative displacement of the sides of the fault, for miners would never accept the change; and, moreover, with the great majority of faults the true relative displacement of the sides would never be known and the word could not be used at all; when this displacement is known it can be properly designated by the words "slip" or "shift." It is therefore advisable to restrict the word "throw," and with it the word "heave," to the displacements of the ends of a disrupted stratum; and in order to extend the use of the words to oblique faults, we must define the vertical plane in which the two points of the disrupted stratum lie which are to be used to determine them. These considerations lead to the following definitions:

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[20] General methods of determining the slip and shift are given in Geometry of Faults. Bulletin of the Geological Society of America, vol. xx, pp. 171-196, and in Tolman's Graphical Solution of Fault Problems, loc. cit.

The throw is the vertical distance between corresponding lines in the two *fracture surfaces* of a disrupted stratum, etcetera, measured in a vertical plane at right angles to the fault strike.

The heave is the horizontal distance between corresponding lines in the two *fracture surfaces* of a disrupted stratum, etcetera, measured at right angles to the fault strike. These distances must be measured between *corresponding* lines—for instance, between the upper edges of the two *fracture surfaces* of the stratum or between their lower edges—but not between the upper edge of one fracture surface and the lower edge of the other.

In figure 2 the ends of the block are vertical sections at right angles to the fault strike; *fk* is the throw and *ek* the heave. In figure 3, *cg* is the throw and *bg* the heave, if the strikes of the fault and strata are parallel. (See also figures 15, 16, 17.) The words "throw" and "heave" have been used in various senses. A. Geikie uses "throw" for the distance (*ec*, in figure 9), which we have called the vertical separation, and Spurr for the separation along the dip of the fault plane. J. Geikie, Willis, Scott, and Fairchild use "heave" practically as it is defined above. A. Geikie and Spurr make it equivalent to the offset. Jukes-Brown apparently used it for the strike-slip (de Margerie and Heim, page 72); so did Ransome, and Scott also uses it in this sense when he refers to "heave-faults." The throw has also been called the "vertical throw" and the heave the "horizontal throw," but this usage is not recommended.

APPARENT DISPLACEMENTS

It is often desirable to refer to the apparent displacement in a particular vertical section. For this purpose it is convenient to use the expressions *apparent slip, apparent throw,* etcetera. The context should, of course, show what vertical plane is under consideration. It is never necessary to use the word "apparent" in connection with the separation, as the separation can be measured in any given direction.

FAULTS CLASSIFIED ACCORDING TO THE DIRECTION OF THE MOVEMENT

Faults may be classified, according to the direction of the movement on the fault plane, into

Dip-slip faults, where the net slip is practically in the line of the fault dip.

Strike-slip faults, where the net slip is practically in the direction of the fault strike. J. Geikie calls such faults "transcurrent faults," or "transverse thrusts." Jukes-Brown calls them "heaves." Scott calls them "horizontal faults" or "heave faults." A vertical fault is one with a dip of 90 degrees (see below); and, by analogy, a horizontal fault should be one with a zero dip and should not refer to strike-slip faults.

Oblique-slip faults, where the net slip lies between these directions.

CLASSES OF STRIKE FAULTS

Most geological text-books and books on field methods have confined themselves almost exclusively to the discussion of dip-slip faults, and have given little attention to the other two classes.

Strike faults have usually been treated as though they were also dip-slip faults and classified into

Normal faults, where the hanging wall has been depressed relatively to the foot wall.

Reverse faults, where the hanging wall has been raised relatively to the foot wall.

Vertical faults, where the dip is 90 degrees.

The relative displacement has usually been determined by means of a dislocated bed. Although exception may well be taken to these terms, their retention is recommended, because they are in general use and are well understood. The word "reverse" is preferable to "reversed" (which has been almost universally used), as the latter implies the reversal of an action.

The horizontal distance between two points on opposite sides of a fault, measured on a line at right angles to the fault strike, is always shortened by a reverse strike fault, lengthened by a normal strike fault and unchanged in length by a vertical fault.

EXTENSION OF THE WORDS "NORMAL" AND "REVERSE" TO DIAGONAL AND DIP FAULTS

The expressions "normal" and "reverse" may be used in connection with oblique and dip faults, even when they are strike-slip or oblique-slip faults, provided they are applied to designate the apparent relative displacement of the two parts of a dislocated stratum, or other recognized surface, in a vertical plane at right angles to the fault strike. It does not follow, in the case of oblique-slip faults, that a horizontal line at right angles to the fault strike would be lengthened by a normal or shortened by a reverse fault. This has been pointed out by Mr. Ransome[21] and may be illustrated by figures 7 and 8. In figure 7 a reverse fault, as determined by the displacement of the stratum, has caused an extension at right angles to the fault strike. It is evident that if the hanging wall had moved, as in figure 8, with the stratum dipping as there represented, we should have had a normal fault and a contraction at right angles to the fault strike. The relations of the two parts of the disrupted stratum in figure 7 are exactly the same as if we had had a simple reverse dip-slip fault, and in figure 8 as if we had had a simple normal dip-slip fault; and if there were no disrupted dikes or other means of determining the amount of the strike-slip, the movements described could not be distinguished from simple dip-slip faults. It very frequently happens that nothing more than the apparent displacement of the strata can be determined, and we recommend that the terms "normal" and "reverse" faults as defined be used purely for purposes of description and not for the purpose of indicating extension or contraction, tension or compression, vertical or horizontal forces. John A. Reid has suggested that the terms "apparently normal" or "apparently reverse" fault be used until it has been definitely made out whether the hanging wall has experienced a relative movement up or down the fault dip, and then to use the terms "normal" or "reverse." The objection to this is that it breaks with former usage and introduces confusion, for the distinction would certainly not always be made.

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[21] Economic Geology, vol. 1, pp. 783-787.

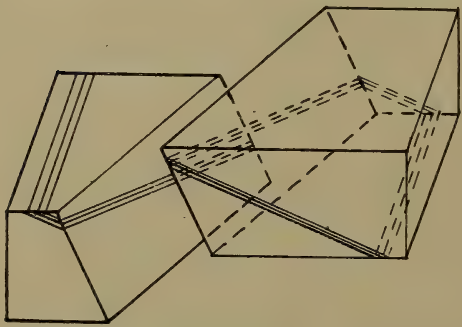

FIGURE 7.—*A reverse Fault due to an oblique Slip.*

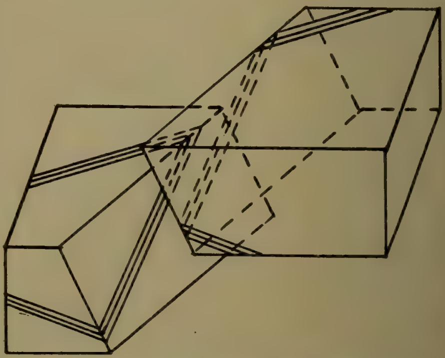

FIGURE 8.—*A normal Fault due to an oblique Slip.*

SPECIAL CLASSES OF FAULTS

There are two kinds of faults which have played such important rôles in altering the structure of some regions that they have received special names.

Overthrusts: These are reverse faults with low dip or large hade. In some cases the dip-slip has been enormous, amounting to tens of kilometers. Scott calls them "thrusts" and separates them entirely from faults of high dip; but the word "thrust" has been used for ordinary reverse faults of high dip. The word "overthrust" has been very generally used for this kind of fault and is very descriptive. It should be adopted.

Flaws: Suess has described with care certain faults in which the strike is transverse to the strike of the rocks, the dip high and varying from one side to the other in the course of the fault, and the relative movement practically horizontal and parallel with the strike of the fault. He has used the word "blatt" (plural, "blätter") to designate them. Miss Sollas has used the word "flaw" in the English translation of Suess.

ROTATORY MOVEMENTS

As has already been pointed out, the displacements of all large faults will be accompanied by a rotation varying in amount along the course of the fault; moreover, in some cases the general character of the displacement may be rotatory, although the rotation will not be uniform along the fault. Where rotations occur, the amount of rotation of the *part* under consideration and the direction of the axis should be given. Rotatory movements on faults have been but little studied, and it is not considered advisable to suggest a special nomenclature at present. Faults with rotatory movements have been called "pivotal" faults; but this term is not satisfactory, as there are no pivots.

GROUPS OF FAULTS

It seems unnecessary to define all combinations of faults. The words in common use are sufficiently consistent and universal not to cause confusion. There is one group, however, that might advantageously be defined. Where a mass is elevated or depressed, it is sometimes surrounded by one set of faults, cut approximately at right angles by a second set.

Peripheral faults are faults running along the periphery of a geologically elevated or depressed region.

Radial faults are faults radiating roughly from a point. Each of these two groups of faults may exist without the presence of the other. Scott has divided all faults into "thrust," "radial," "horizontal," and "pivotal" faults; the first have been called "overthrusts" above, and the next two are roughly our dip-slip and strike-slip faults of high dip. By the word "radial" Scott apparently refers to the directions of the earth's radii.

The former use of the word "radial" is older and more general than Scott's and should be adopted.

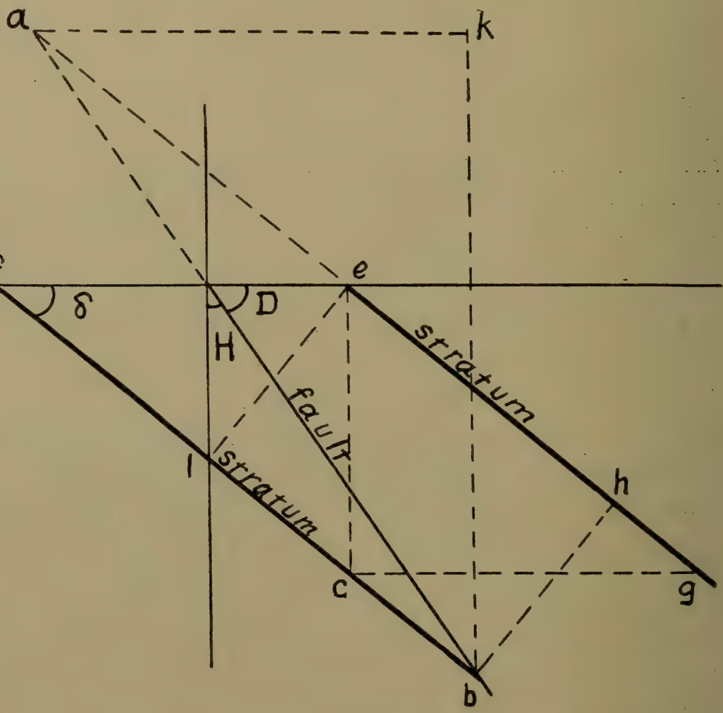

FIGURE 9.—*Section of a reverse dip-slip Fault*

(Legend for figures 9, 10, 11, and 12)

ab = slip
bk = throw
ak = heave
el or *bh* = stratig. separ.
ec = vertical separation
bg or *cg* = horiz. separ.
δ = dip of strata
D = dip of fault
H = hade of fault

$$\frac{\text{vert. separ.}}{\text{hor. separ.}} = \tan.\ \delta$$

$$\frac{\text{strat. sep.}}{\text{hor. sep.}} = \frac{\text{strat. sep.}}{\text{offset}} = \sin.\ \delta$$

$$\frac{\text{strat. sep.}}{\text{vert. sep.}} = \cos.\ \delta$$

$$\frac{\text{throw}}{\text{heave}} = \tan.\ \text{D} = \cot.\ \text{H}$$

$$\frac{\text{throw}}{\text{slip}} = \sin.\ \text{D} = \cos.\ \text{H}$$

$$\frac{\text{heave}}{\text{slip}} = \cos.\ \text{D} = \sin.\ \text{H}$$

$\frac{\text{strat. separ.}}{\text{slip}} = \sin\ (\text{D} \pm \delta)$; the proper sign to take will appear from the triangle *a b h*.

SPECIAL TERMS

The following terms refer to the displacement on faults and do not refer to the form of the earth's surface. They denote geologic structure, not topographic form.

A horst is a mass elevated relatively to the surrounding masses and separated from them by faults.

A graben is a mass depressed relatively to the surrounding masses and separated from them by faults.

A fault block is a mass bounded on its sides, completely or in part, by faults. It may be elevated or depressed relatively to the adjoining mass, or it may be elevated relatively to the mass on one side and depressed relatively to that on the other. A mass that is not entirely inclosed by faults may properly be termed a fault block only when it can be regarded as a structural unit whose relations to the adjacent masses has been dominantly determined by faulting.

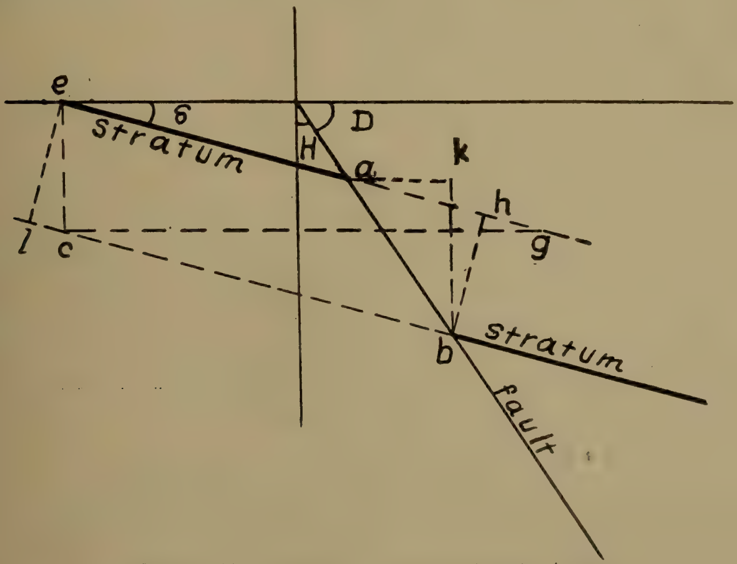

FIGURE 10.—*Section of a normal dip-slip Fault*

(See figure 9 for legend)

The pitch of a line lying in the fault-plane, such as the trace of a dislocated bed or vein, is the angle between the line and the horizontal measured in the fault-plane. The angle between the same line and the horizontal measured in a vertical plane through the line is the *dip* of the line.

SUGGESTIONS FOR TEACHING [22]

The extent of the instruction on the subject of faults and their nomenclature must be determined by the character of the class and by the judgment of the instructor. It would be sufficient to give elementary students a general conception of a fault as a fracture dying out at the ends and varying along its course in the amount, direction, and character (translatory or rotatory) of the displacements. The terms defined in the sections on General Terms and General Classes of Local Movements or

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[22] This section has been added at the request of several Fellows of the Society. It must necessarily be concise.

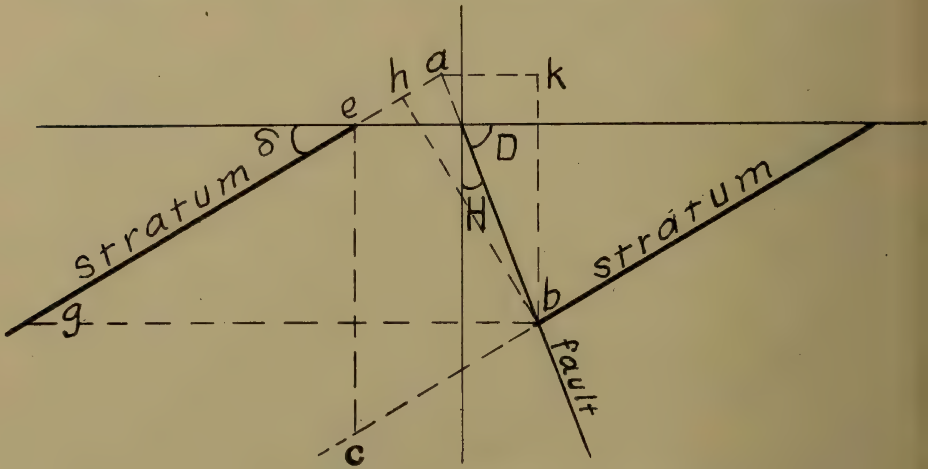

FIGURE 11.—*Section of a normal dip-slip Fault*

(See figure 9 for legend)

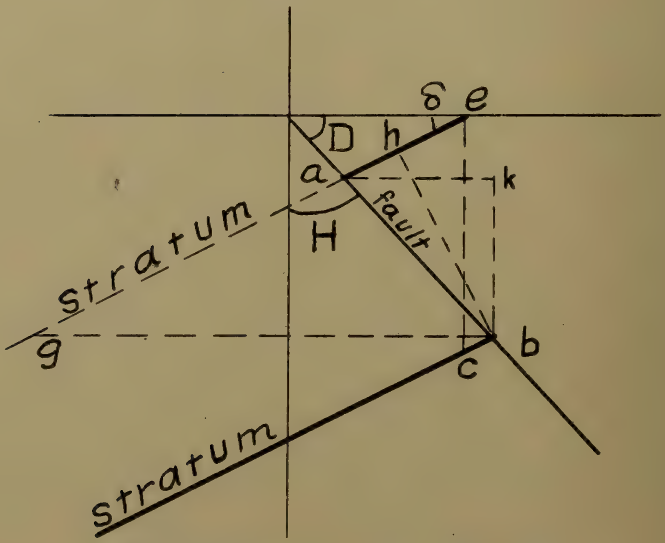

FIGURE 12.—*Section of a reverse dip-slip Fault*

(See figure 9 for legend)

Faults might be introduced in order to make the conception of a fault more accurate and precise.

With a more advanced class the local displacements in the different parts of the fault should be described and their characteristics discussed, beginning with a dip-slip fault (the simplest type of fault and fault-movement), all of whose elements can be shown in a vertical section taken at right angles to the strike of the fault and of the strata. With the help of figures 9, 10, 11, and 12, which are sections of this kind, the various elements of the displacement should be defined, and the relations between them, as given below the figures, should be brought out. The characteristics of vertical, normal, and reverse faults should be pointed out, and it should be shown that the outcrops of the strata will be repeated on opposite sides of the fault if the strata dip toward the upthrow side of the fault, and that some strata will not outcrop at all if the strata dip toward the downthrow side of the fault. This may be illustrated by figures 13 and 14, which represent vertical faults. It is quite evident that if the fault should dip to the right we should have a reverse fault, and if to the left a normal fault. There would be no change at the surface if the fault-line were not moved. Unless the dip of the fault can be found, surface observations will in many cases not decide whether the fault is normal, vertical, or reverse.

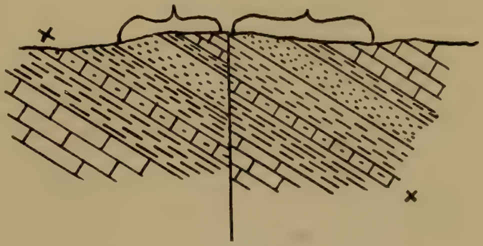

FIGURE 13.—*Beds repeated at Surface*

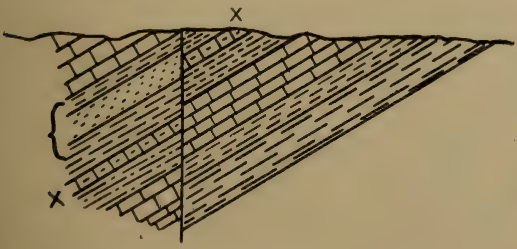

FIGURE 14.—*Beds missing at Surface*

Strike, dip, and oblique faults should now be defined and an oblique fault considered as the general case of all three. Figures 15, 16, and 17 show the displacements in plan and in two sections. It is necessary here to define apparent displacements and to describe the relations of the two branches of the outcrop as dependent on the directions of the strike of the fault and of the strata, defining also the gap and overlap.[23]

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[23] These relations are well illustrated in Chamberlin and Salisbury's Geology.

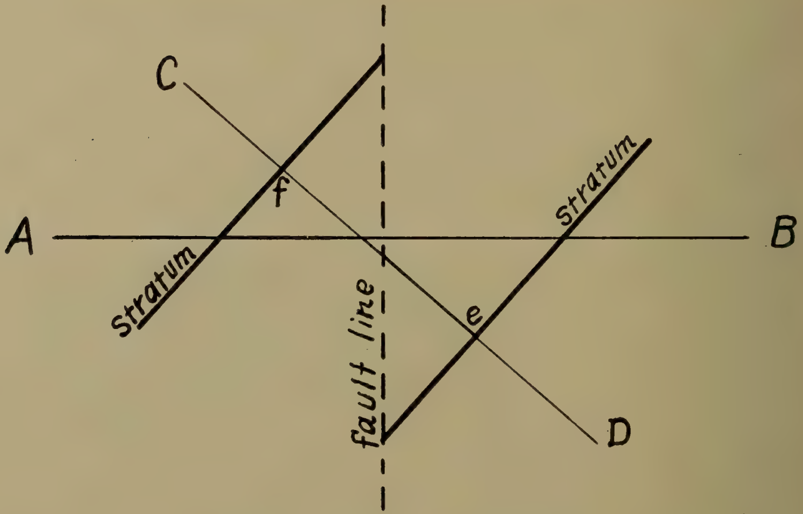
C
f
A
Stratum
Stratum
B
e
fault line
D

FIGURE 15.—*Plan of an oblique Fault*

ef = offset

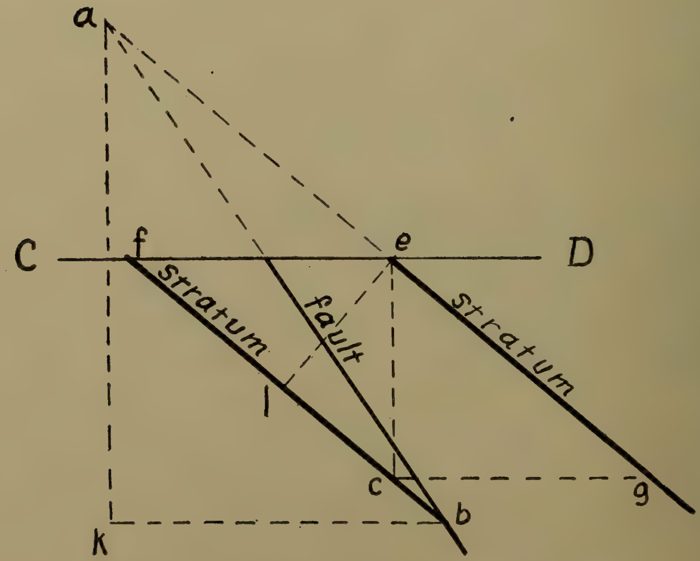
a
C
f
e
D
Stratum
fault
Stratum
l
c
g
b
k

FIGURE 16.—*Vertical Section at right Angles to Strata*

ef = offset
ab = apparent slip
el = stratig. separ.
ec = vertical separ.
cg = normal horiz. separ.
ak = apparent throw
bk = apparent heave

Dip-slip faults alone have been considered up to this point, and it is probably not desirable to go more deeply into the subject except with special students in geology or mining engineering. With special students the more complex part of the subject should be taken up as follows:

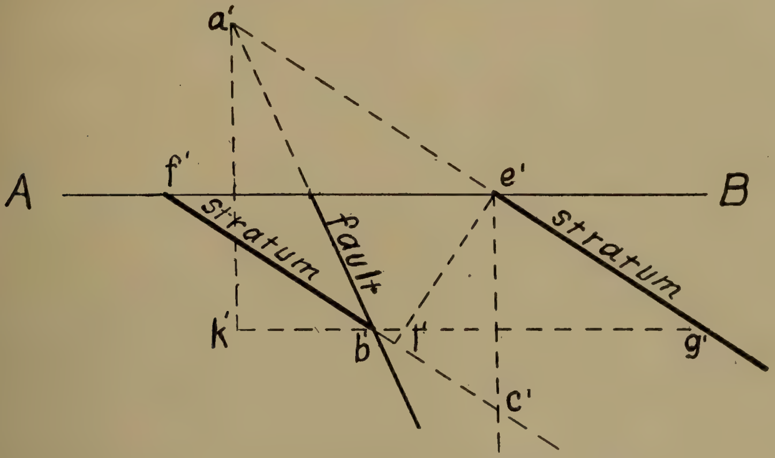

FIGURE 17.—*Vertical Section at right Angles to Fault*

a′ b′ = slip for dip-slip fault
a′ b′ = appar. slip for oblique-slip fault
e′ f′ = appar. offset
a′ k′ = throw
b′ k′ = heave
e′ l′ = appar. strat. separ.
b′ g′ = hor. separ. in this plane.
e′ c′ = vert. separ.

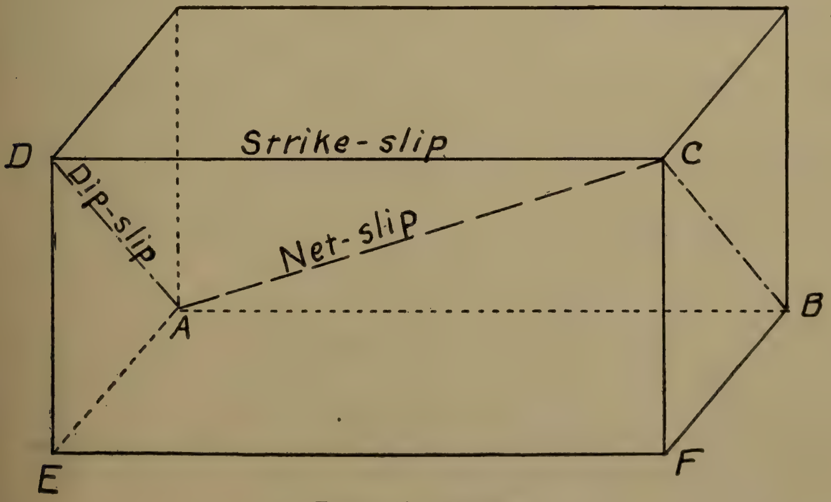

FIGURE 18.—*The Slip*

Experience shows that movements may take place in any direction on a fault surface, and this leads to the definition of dip-slip, strike-slip, and oblique-slip faults. An oblique-slip fault, as the most general case of fault movement, may be illustrated by figure 18. The block represents a portion of the earth's crust; its boundary lines have no real existence in nature, but are drawn for the purpose of indicating directions and showing the position of the fault surface. Suppose, then, that a fracture takes place in the surface *ABCD,* and suppose that the point which was formerly immediately adjacent to *A* should move by faulting to *C;* then *AC* would be the slip or net slip, *DC* the strike-slip, and *AD* the dip-slip.

The fault-plane is completely defined locally if we know its strike and dip and one point of its plane, such as a point of its outcrop. As the movement takes place parallel with the fault-plane, we need only two components of the motion in this plane completely to define the displacement; the strike-dip, *DC,* and the dip-slip, *AD,* are suitable components; but it may be convenient at times to use the trace-slip and the perpendicular slip. To determine the slip it is necessary to identify the original and final position of a point; this is frequently impossible, and then the slip can not be found.

The displacements of strata, dikes, etcetera, are the displacements usually determined, and in some mining operations they are all that is needed. They are described by means of the separations, which must be defined. Figures 7 and 8 show that they frequently give no clue to the slip. If the offset or the normal horizontal separation and the dip of a bed have been found, the stratigraphic separation can be calculated and the relation of the two branches of a stratum becomes known. The vertical and horizontal separations can be determined in shafts and drifts of mines.[24] The generalized definitions of throw and heave and of normal and reverse faults find their places here.

Where the strata near the fault have been distorted by the movement and bent up or down, the displacement of the crust outside the distorted position is not the same as the slip; this leads to the definition of the shift. Note that in strike faults without a distorted zone the heave shows the amount of horizontal contraction or extension of the crust due to the fault. In the general case this contraction or extension is shown by the normal shift, which, where there is no distorted zone, becomes equal to the corresponding component of the slip.

Finally, the relations existing in groups of faults should be explained, and such special terms as flaw, horst, graben, etcetera, should be defined.

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[24] In a former foot-note references have been given to the methods necessary for the determination of the slip. The subject is too extensive to be treated here.

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NOMENCLATURE OF SURFACE FORMS ON FAULTED STRUCTURES[1]

BY W. M. DAVIS

(*Presented in abstract before the Society December 28, 1912*)

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GEOLOGICAL AND PHYSIOGRAPHICAL NOMENCLATURE OF FAULTS

The geological nomenclature of faults is chiefly concerned with a geometrical treatment of local problems of underground structures, and gives little or no consideration to surface forms. The physiographic nomenclature of faults is concerned almost wholly with large topographical problems of surface forms as determined by the action of erosional processes on faulted structures. The terminology here suggested for surface forms of this class is closely related to a systematic method of physiographic description which may be called the method of "structure, process, and stage," in that it recognizes, first, the underground structure—often called the geological structure—of the mass which exhibits physiographic forms in its upper surface; second, the process or processes which have worked on the structural mass so as to modify its initial surface forms; and, third, the stage reached by the action of process on structure in producing the actual forms under consideration, in view of the whole series of stages from the initiation of erosional work by the uplift of the structural mass to the completion of erosional work by the reduction of the mass to a featureless plain. Relief, or local inequality of altitude, and texture, or spacing of stream-lines, are also given explicit attention in the fully developed application of this systematic scheme, but they will not be closely considered here. As the proposed terminology for surface forms on faulted structures is thus related to a comprehensive plan of treatment for all sorts of forms on all sorts of structures, the terms can not be well understood from definitions alone. Their meaning can be better gathered from the following statement of the manner in which they are used.

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[1] Manuscript received by the Secretary of the Society April 28, 1913.

Presented orally in abstract December 28, 1912, as a discussion of the report of the Committee on Nomenclature of Faults.

THE CYCLE OF EROSION

It appears from the foregoing that an important feature of the scheme of "structure, process, and stage" is the recognition of the systematic sequence of surface forms that must be developed during the progress of erosional work on structural masses. Various essential terms in the scheme are related to the sequence in which surface forms are produced, and the chief of these will now be concisely stated. The time required for the completion of the whole series of erosional changes, between the initiating uplift of a land-mass and its ultimate reduction to a featureless lowland or to a submarine platform, is called by American physiographers a cycle of erosion; and all the members of the systematic sequence of forms produced during the normal progress of a cycle of erosion may therefore be called sequential forms—the three terms, initial, sequential, and ultimate, so appropriately related to one another in this scheme, having been first introduced by Dr. F. P. Gulliver in his study of "Shoreline Topography" ('99).

It has become to be habitual with many physiographers to speak of the early, intermediate, and late members of such a sequence as young, mature, and old; and to speak of the early, intermediate, and late stages of a cycle as its youth, maturity, and old age—two of these biological terms having been employed in this connection nearly thirty years ago by Chamberlin and Salisbury in their description of the "Driftless Area of the Upper Mississippi Valley" (**'85,** 229), although what was there described as "old age" is here called "maturity." Evidently a cycle of erosion thus conceived is not a definite measure of time, but simply such a duration as suffices for the accomplishment of the task initiated by uplift; just as the cycle of life for an organic form is not a definite number of days or years, but simply a time sufficient for passing through all the stages of growth in a completed life. Similarly when a certain sequential form is described as young or mature or old, no definite measure of time or number of years is to be understood, but only such a part of the total duration of the cycle concerned as corresponds to its earlier, middle, or later development. A young Sequoia might be older than a mature man, and a mature man much older than an old mushroom, because the terms young, mature, and old, even when indicative of age, are always considered in relation to the normal length of life of the individual under consideration; or, as Kant put it over a hundred years ago: "Wenn man wissen will, ob ein Ding alt, ob es sehr alt, oder noch jung zu nennen ist, muss man nicht nach der Anzahl der Jahre schätzen, die es gedauert hat, sondern nach dem Verhältnis, dass diese zu derjenigen Zeit gehabt haben, die es dauern solte" (Sämmtliche Werke, I, 1867, **189**).

INTERRUPTIONS OF THE CYCLE OF EROSION

The progress of changes through a cycle of erosion may be interrupted at any stage, if the land-mass is displaced so as to take a new position with respect to the controlling baselevel of erosion; the land-mass may be regarded as thereupon entering a new cycle of erosion, the young forms of the newly introduced cycle for a time combining with and then gradually replacing the previously developed forms of the interrupted cycle. Besides the many complications introduced by crustal movements which, following the terminology here employed, may "interrupt" one cycle and "introduce" another, there are other disturbing complications produced by volcanic eruptions or by climatic changes, which do not necessarily involve any change in the attitude of a land-mass with respect to baselevel. It is my personal habit to speak of these disturbances as "accidents," and to reserve the word "interruptions" for crustal movements by which a land-mass is given a new attitude. With accidents we here have nothing more to do. With interruptions, which include uplifts, depressions, warpings, foldings, and deformations of any kind, we are further concerned, because one kind of deformation embraces faults, which involve differential movements of the two parts of a severed mass. The development of a systematic terminology, consistent with the rest of the terminology of the method of "structure, process, and stage," for forms developed on faulted structures is the object of this paper.

Relation of Faults to the Cycle of Erosion

It is manifest from what is known of many well studied examples of faulted structures that a fault may take place in any direction and with any displacement in a structural mass of any kind, at any stage in its physiographic development, under the action of any kind or kinds of erosional processes on its surface. It is also clear that, just as the fault may have any relation to the underground structures that it traverses, so its surface expression in a fault scarp may traverse indifferently all other kinds of surface forms. Further, it follows that on account of the new positions given to the two parts of the faulted mass with respect to base-level, the surface action of the erosional processes must be more or less changed as a consequence of faulting. The cycle of erosion previously current should, therefore, in accordance with the scheme above stated, be regarded as "interrupted" and the further work of erosion be treated as belonging to a new cycle "introduced" by the faulting; but, unless the displacement of the fault be large, so strict an application of the scheme of the cycle is not necessary; small disturbances may be treated as mere episodes of a single cycle. Nevertheless, if a long succession of small faults occur, the sum of their movements must suffice to interrupt the preceding cycle and to introduce a new one, and the work that the erosional processes were previously performing will thus in time come to be seriously modified and an altogether new series of sculptured forms will result therefrom.

In view of the object of that section of modern physiographic study which is concerned with the description of land forms, it is evident that the terminology of surface forms developed on faulted structures must have especial reference to existing surface features that are actually visible. This is hardly more than a truism, yet it deserves conscious recognition and emphasis, because it often happens that in the attempt to give explanatory description to land forms the complications of the past processes involved in the explanation distract the attention of the reader from their visible product in the features of the present landscape and direct it to the past action of inferred processes on invisible structures. This is a real difficulty, which at present seriously embarrasses many physiographic studies; but it is not an insuperable difficulty. One of the readiest means of lessening it is not to neglect it but to attack it—that is, consciously to direct our attention toward the existing surface product of past processes on underground structures—and thus avoid entanglement in the maze of the past processes themselves. Our effort should constantly be turned to telling what a district looks like, whether we tell about it in the empirical terms of an earlier century or in the explanatory terms now more in fashion. The reasons which have led many to follow the explanatory method I have sufficiently set forth in an address of a year ago (*a,* '12, 104-112).

AN IDEAL SERIES OF FORMS ON FAULTED STRUCTURES

Two methods of procedure toward our present object are in use. One consists in gathering the accounts of various actual forms on faulted structures, arranging them in some suitable sequence, and giving them, one after the other, explanatory description in some fitting terminology; these actual examples then serve as types for the description of new examples. Another method begins like the first one with a collection of actual examples, but it goes much farther; it establishes the general principles that are exemplified in the collected cases, and then deduces from these general principles a systematic series of purely ideal examples, and describes them in a correspondingly systematic series of explanatory terms. The second method is here adopted, but only its deductive part is presented in this essay. In passing, it may be pointed out that in the possibility of greatly increasing the number of deduced ideal examples over the number of observed examples, and in the full understanding that is gained regarding the ideal forms, inside and out, in their past, present, and future conditions, lies the great advantage of a deductively developed explanatory terminology. Evidently the description of a new example will be much facilitated if the observer has previously made acquaintance with a large number of thoroughly understood types; and no method yet employed provides so large an outfit of well conceived types as the deductive method here adopted. But it should not be forgotten that the deductive part of this method of establishing a terminology can not be properly undertaken until after an earlier inductive and analytical study of many actual examples has made it possible safely to establish the general principles from which the deduced ideal examples are drawn.

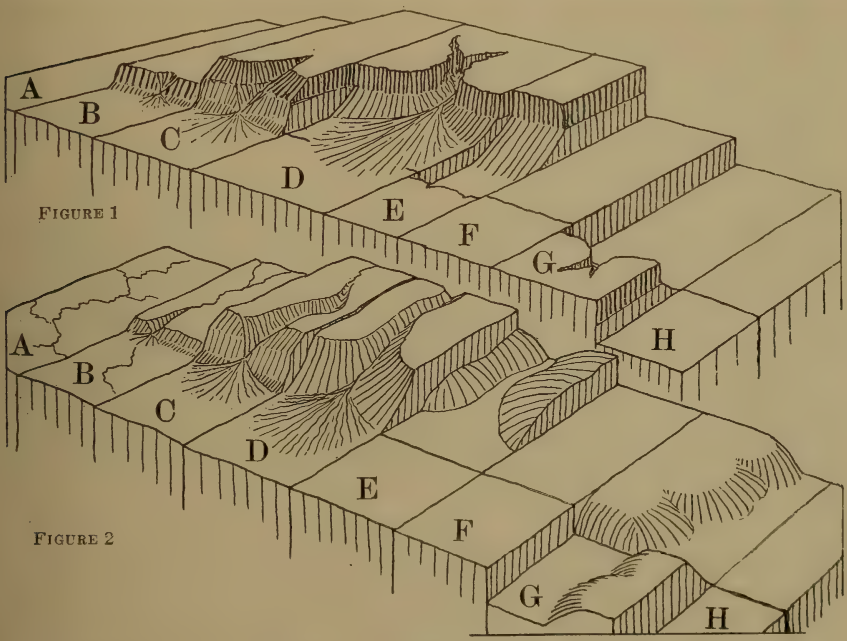
Let us therefore begin the present study at the beginning, or initial stage, of an imagined new cycle of erosion, which is introduced by the strong faulting of a land mass of any structure that has already reached any stage of erosional development in a preceding cycle. Be it noted, however, that the "strong faulting" is not to be understood as accomplished all at once, but by a succession of small faults, each of which alone would be, as already indicated, merely an episode, although all taken together suffice to interrupt the cycle previously current and to introduce the new one. We then follow the sequential changes as far forward through the new cycle and through later cycles as is profitable, and give appropriate names to the more important forms that are associated with the fault at successive stages during successive cycles in the work of erosion on it.

As long as our discussion is presented only in verbal form, its general values, indicated in such phrases as "a land mass of any structure in any stage of development" may be preserved; as soon as a diagram is added to give graphic illustration of verbal meaning the discussion is in danger of losing much of its generality, for a single diagram can show a land form of only one structure and usually of only one stage. Nevertheless, such are the advantages of graphic illustration that diagrams can not be dispensed with; their dangers may perhaps be lessened by using series of composite diagrams, as in figures 1 and 2, the two series having different structures and each series showing a number of successive tages. Figure 3 shows only a single mature stage of a mountainous district of massive structure crossed by recent faults. The variety of faulted structures is evidently endless, yet a comparatively simple scheme of treatment may be adapted to all of them. Step-faults may be best treated by giving separate account of each of their members. Renewed faults may involve several successive interruptions of cycles of erosion instead of a single interruption. Hence all that need be done here is to develop a scheme of treatment for a few simple examples; the scheme may afterward be modified as needed for complex examples.

Initial and young Forms on faulted Structures

Imagine, then, a surface of any kind—for example, a young lava plain, A, figure 1, or a district of subdued or old crystalline hills, A, figure 2, or a mature, mountainous mass of deformed strata, figure 3. Let the surface be traversed by a fault of moderate displacement, producing a low fault scarp, B. For simplicity of introductory discussion, let the lower part of the faulted mass remain for the present in its former attitude with respect to baselevel, so that erosion is revived only in the uplifted part.

In the initial stage of the new cycle thus introduced the physiographic account of a fault should always begin with the description of the surface previous to faulting; then proceed with a statement of the aspect, direction, length, and altitude of the fault scarp (or "vertical separation" of the two parts of the prefaulting surface), with special mention of significant local details—for example, the manner in which ridges and hills are divided, valleys displaced, and streams ponded or accelerated, as well as of local complications in the scarp caused by the doubling or splitting of the fissure—or, in brief, the account should state *the prefaulting surface and the effects of faulting.*



FIGURES 1 AND 2.—*The Sequence of Forms developed on faulted Structures*

This procedure is in accord with a general principle of prime importance in the explanatory description of land forms, namely, whenever a movement of a land mass enters into its description—as in the case of a regional uplift, a fault, or a coastal subsidence—the thing that suffered the movement must be described as well as the movement of the thing: otherwise the visible landscape as affected by the movement can not be conceived; and the prefaulting forms should be described, by those who adopt the method of "structure, process, and stage," in terms of these three factors—that is, its general structure should be stated, the processes that have worked on it should be announced (except that if it has been worked on only by the ordinary or "normal" process of weather and water this may be understood without explicit announcement), and the stage reached by the action of process on structure should be indicated. Although the principle here involved is simple in essence and of evident value, it is very commonly neglected. An explorer may say that a coastal district has suffered submergence, and yet fail to tell what the form of the district was before submergence; thus he leaves his readers in the dark instead of enlightening them as to the present coastal forms. Another explorer may say that a district is traversed by a recent fault, and yet fail to tell what the form of the district was before the fault took place; his readers are then left too little informed and are unable to conceive the landscape that the explorer has traversed.

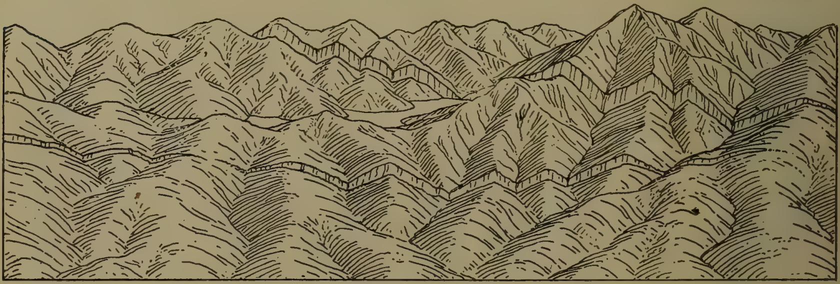


FIGURE 3.—*Young Faults in a Mountainous District*

If the surface of the lower mass is plain and gently inclined toward the fault, the longitudinal depression thus produced may be called a fault trough; a stream consequent on the faulting will then soon erode a fault valley. But if the faulted surface is hilly or mountainous, as in figures 2 and 3, no continuous fault trough will be formed by the faulting, and the irregular relief along the scarp base will cause any streams that may flow for a short distance along the fault line to depart from it sooner or later and perhaps to leave it altogether.

If the surface of the uplifted block is of small relief and is inclined by the faulting, new consequent streams may be formed on it; but this can only be the case when the prefaulting slopes are weak and the faulting is rapid enough to extinguish the preexisting streams. New consequent streams might be expected on the inclined surface of the upfaulted lava plain, figure 1 B, but not on the rolling or mountainous surface of figures 2 and 3. In these two cases any new slant given to the upfaulted masses will, instead of developing new consequent streams, merely favor the headward erosion of those whose slope is increased and discourage it in the others, as Campbell has pointed out in his discussion of "Drainage Modifications and their Interpretation" ('96).

The face of an initial scarp is rapidly changed into a young consequent scarp by the loss of waste, which slips, creeps, and washes down to the scarp base, there accumulating in landslides, talus slopes, and alluvial fans, which bury the fault line. Even if a stream is initially formed along the fault line, as in special cases above indicated, it is liable soon to be pushed away by the abundant down-wash of waste from the scarp; hence if such a stream afterward cuts a valley, the valley is not likely to follow closely along the fault line.

If faulting is soon renewed, the scarp will be refreshed and its base kept close to the fault line, as in figures 1 C and 2 C, although its earlier exposed upper slope will have retreated somewhat from its initial position. The details shown in figure 1 C are highly suggestive of a second uplift, which took place some time after the first, for here the face of the covering lava sheet is worn back to a slope, while the face of the underlying weaker strata is steep. During the retreat of a scarp it must take on details of form appropriate to its structure. Details of this kind may be called subconsequent if they do not depart greatly from the pattern of the initial scarp, or subsequent if they include altogether new features developed by the action of erosion on inclined structures of strongly different resistance. These details are, however, not limited to retreating fault scarps; they would be equally well developed on the two retreating walls of a young river-cut valley.

THE ESSENTIAL PRINCIPLE IN THE PHYSIOGRAPHIC DESCRIPTION OF FAULTS

It thus appears that a physiographic description of a fault in an early stage of the cycle that it has introduced should include an account of the prefaulting surface and of the fault scarp, as before stated, and to these two headings a third should now be added, under which the features developed after faulting—that is, the youthful features of the new cycle—are described in their systematic modification of the prefaulting features. Here again we find application of the same general principle of explanatory description that was mentioned above, but now extended so as to include three terms, namely, the post-movement features as well as the pre-movement features and those directly due to the movement itself.

Simple as this extension of the principle is and manifest as is its value, it is repeatedly overlooked. The explorer who describes a coastal district as having suffered submergence too commonly fails to tell what changes have taken place since and on account of submergence, just as he fails to describe the landscape that existed before submergence; yet it is nearly always the case that along a certain line of the pre-submergence forms—namely, the new shoreline—certain post-submergence features in the form of bayhead deltas and headland cliffs have been more or less developed. Likewise, the explorer who describes a district as traversed by a fault usually fails to make explicit statement of the changes that have taken place since and on account of faulting, as well as of the prefaulting forms, in which the post-faulting changes have occurred. The establishment of some systematic method for the explanatory description of land forms will go far toward correcting these omissions; in my own experience the method of "structure, process, and stage," here outlined in its relation to forms developed on faulted structures as well as on other structures, has repeatedly proved helpful in field work, and it is therefore the more confidently recommended to others.

EXAMPLES OF INITIAL AND YOUNG FAULT SCARPS

Various reports of the United States Geological Survey on the Great Basin province furnish us with the best described examples of initial and young fault scarps in this country, the initial scarps being in most or all cases the result of renewed movement on earlier faults. Several striking cases of earlier faults are described by Russell (**'84**,) in southern Oregon, where the prefaulting mass was a broad plain of lava flows resting unconformably on a floor of more or less eroded crystalline rocks, and where a series of north-south faults has broken the mass into long blocks which have suffered strong differential displacement, the upraised block-edges being now more or less carved into mountainous ridges, while the relatively depressed areas are buried under plains of alluvium. Some of the scarps are "slightly scarred by erosion;" others are elaborately carved. The fault along the eastern base of one of the largest mountain blocks is about 100 miles in length, "with a displacement where the mountains are highest of not less than 5,000 or 6,000 feet;" and at one point "there has been a very recent movement along the old fault. The irregular scarp in alluvium formed by the recent displacement is fresh and unclothed with vegetation, and may be traced for several miles at the immediate base of the mountains, defining the boundary between swampy meadows [on the east] and solid rock [on the west]. The hade of the recent fault is to the eastward at a high angle, while the throw, as shown by the fresh scarp, is from 20 to 50 feet" (445). Another line of displacement "is marked by numerous hot springs and by fresh fault scarps, from 20 to 50 feet high, that cross alluvial cones and cut embankments and terraces" (449). Some of the greater fault scarps, "forming the mountain faces, are in many instances nearly vertical walls, hundreds of feet in height, of such recent date that they have scarcely been notched by erosion, and have but small, if any, alluvial cones at their bases" (436). No details are given as to the special forms developed in the more elaborately dissected scarps. One of my own papers refers to part of the same district (*b*, **'03**, 164–). Koto (**'93**) has described and figured an extraordinary scarp in Japan produced by the earthquake of 1891. Tarr and Martin (**'06**) have done the same for scarps in Alaska produced by the earthquake of 1899.

MATURE FORMS ON FAULTED STRUCTURES

In the cases here figured the early post-faulting changes are, in figure 1 D, chiefly the retreat of the scarp by weathering and the incipient dissection of its face by short, wet-weather streams consequent on the faulting; or, in figure 2 D, by the much more rapid incision of the scarp face by the uplifted streams that flow down from it; in both these cases the burial of the scarp base under alluvium; or, in a later stage of figure 3, the concealment of parts of the scarp in the alluvial deposits of small lakes ponded by the rise of the uplifted mass across the valleys of pre-existent streams that flow toward the uplift. The later or mature post-faulting changes will include the further retreat of the scarp, and with this the development of various details in the scarp face by the subconsequent or subsequent modification of its initial form, as already mentioned; also the deeper incision of valleys in the uplifted mass either by new consequent streams or by revived pre-existent streams; but be it noted that the young or submature valleys here referred to must always be described as modifying the pre-faulting surface in which they are incised, as long as the remnants of the earlier surface constitute a significant part of the landscape. The pre-faulting surface must be explicitly included in the description of the faulted district as long as there are any manifest signs of it.

It is evident that as long as waste is abundantly washed down from the uplifted mass no continuous stream and valley are to be expected along the fault line, even in the more advanced stages of the new cycle, unless highly specialized initial conditions have favored their development; and as such specialized conditions must be rare, the occurrence of consequent streams and valleys along fault lines in a youthful or mature stage of the cycle introduced by the faulting must also be rare. Hence, when a stream valley is found to follow a fault line, it probably has some other than a consequent origin.

In examples of faults of moderate slip that traverse uniform or massive structures at such a stage of the pre-faulting cycle as permits medium or strong relief, the post-faulting erosion may obliterate the fault scarp long before the relief is subdued or reduced to small measure: but where rocks of different kinds are brought together, the fault will long be marked by a change of form following the fault line long after the pre-faulting surface is worn away. If this change of form is a slope, more or less perfectly graded, descending to the relatively depressed side, it may be called a resequent scarp; if it descends toward the relatively uplifted side, as must be the case when weaker rocks occur on that side, it may be called an obsequent scarp, these terms being further explained below. If the fault has produced a belt of breccia, it may be followed by a subsequent ravine, which will often have a peculiar appearance from pitching obliquely down the slope that it dissects; this topic also will be further discussed below.

PHYSIOGRAPHIC EVIDENCE OF FAULTING

Let a special case now be considered, in which the lower side of a faulted mass suffers depression, while the upper mass suffers elevation. As a result the waste washed down from the uplifted mass will tend to accumulate heavily on the depressed mass; at first only near the base of the fault scarp; later on, advancing farther and farther from it and, if the relief of the depressed block be small, burying its surface more and more completely. In such cases the evidence of faulting will not be found in the relative displacement of corresponding structures on the two sides of the fault line, for all outcrops on the lower side will be buried, possibly for miles away. The existence of the fault at this early stage is inferred simply from the form of the scarp by geologists and geographers alike. As long as the scarp which limits the higher mass is strong and little dissected, the existence of a fault would probably be accepted on this evidence by geologists as well as by physiographers; but as dissection progresses and the continuity of the scarp is more maturely interrupted, the evidence of faulting is less immediately apparent; the occurrence of a fault may indeed then be doubted by geologists who give little attention to the evidence presented by land forms and who depend instead wholly on displaced structures; hence the physiographic features which demonstrate faulting in a dissected fault scarp that rises from a waste-covered lowland deserve special attention.

The incision of the initial scarp by ravines, which increase in depth as the scarp is increased in altitude by repeated faulting, will in time destroy its continuity, and when the total uplift has reached a thousand feet or more nearly all the face of the scarp will have been consumed between the slanting ravine walls; but so long as recent renewal of faulting holds the base of the scarp close to the fault line, the spurs into which the greater part of the scarp has been transformed must terminate in triangular facets. The slanting surface of the facets, not much worn back from the fault surface, must truncate the structure of the uplifted mass in such a way that the bases of all the facets stand along a single simple line.

As long as such facets are well defined, there need be no doubt about their marking a fault, even if no rock outcrops are seen on its lower side. The chain of evidence in such a case is indeed of the essentially same nature as that on which geologists usually rely for the demonstration of faulting, although composed of different links. The usual geological evidence of faulting is the occurrence of corresponding structures in discordant attitudes on the two sides of a line; the fault fracture is seldom seen, unless revealed by mining, and the movement implied in the term fault is never seen. In view of such an occurrence, a geologist would say: "Those two corresponding structures can not have been made independently; they must be two parts of an originally single mass, now fractured and displaced by a fault." And this inference of fracturing and displacement in the unobservable past is commonly spoken of in geological circles as if it possessed the same order of verity as the directly observable occurrence of the two discontinuous structures—that is, it is commonly treated as a "fact."

The physiographic evidence of faulting in the case here considered is the occurrence of a highly specialized group of forms, namely, the terminal facets of a series of spurs, peculiarly related to each other and to the structures that they truncate. In view of such an occurrence, a physiographer would say: "Those facets can not be the original termination of the structures that they now truncate; the action of the sea being excluded, no process of erosion can have worn back a former greater extension of the structural mass to so systematic a termination in triangular facets along a simple, non-structural line; hence the visible mass must be part of an originally greater mass, the other part of which has been relatively faulted down out of sight." This inference of fracturing and displacement is not today universally spoken of in geological circles as if it possessed a high degree of verity; but there was once a time when even the orthodox geological evidence of faulting, based on displacement of corresponding structures, also failed to command general acceptance among geologists.

After faulting ceases the terminal facets of fault-scarp spurs will lose their sharpness of form; their edges will be rounded off, their faces will be worn back from the fault line, and although they may still for a time be arranged along a comparatively simple line indifferent to the structure, the unequal retreat of spurs of different resistance must eventually bring about an increasing irregularity in their ending. If the lowland forward from the irregularly retreating spurs is then still covered with transported waste, as frequently happens, the evidence of the fault will weaken, just as the usual geological evidence of a fault weakens when the outcrops by which it is ordinarily proved are covered by transported waste. But in either case, if the transported waste is removed and the rocks or their local soils are revealed, the evidence of faulting becomes manifest by the difference of soils on the two sides of a simple line, as in the cases already stated above.

EXAMPLES OF MATURELY DISSECTED FAULT SCARPS

The western face of the Wasatch range in Utah and the eastern face of the Sierra Nevada in California are regarded by various observers as fault scarps of great dimensions, more or less elaborately dissected. The latter example is largely composed of massive crystallines and, as far as it has been described, does not seem to present subsequent details due to erosion guided by exposed structures; the former example is largely composed of disordered stratified formations and is marked throughout by an abundance of subsequent details. Gilbert (**'90,** 340–) has briefly described the main scarp of the Wasatch, but has given more attention to the signs of recently renewed faulting along the scarp base. Huntington and Goldthwait (**'04,** 230) have studied the southern part of the Wasatch scarp; and in my own papers are some details regarding its middle part, which near Provo exhibit some well preserved terminal spur facets (*b*, **'03,** 152), and near Nephi some striking subsequent features oblique to the trend of the scarp (**'05,** 21); also some account of more maturely dissected scarps along the western sides of the Canyon and House ranges (**'05,** 29–, 46–). Diller has presented short statements regarding the repeated scarps of the northern Sierra Nevada (**'86,** 12), and Russell (**'89,** 279) regarding the great single scarp farther south, in the neighborhood of Mono lake. More recently Reid (**'11,** 114) has described strong scarps in the Lake Tahoe district. Lawson (**'12**) adds details regarding fault facets and recent scarps in the same neighborhood. Louderback (**'04,**) has given a valuable account of the Humboldt Lake mountains, and Baker (**'12,** 130) has lately added a study of El Paso range, both of these being members of the Great Basin system and both possessing dissected fault scarps on one side.

McGee (**'89,** 616) some years ago described the submaturely dissected scarp along the inner border of the Atlantic coastal plain in Maryland. Twenhofel (**'12,** 20) has lately described a strong scarp on the northwestern border of Newfoundland as due to faulting followed by a moderate amount of erosion; but his account does not exclude the explanation of this feature as a resequent fault-line scarp, here set forth in a later paragraph.

The broad valley, or graben, of the middle Rhine is inclosed by maturely dissected scarps. The one on the east, forming the western face of the Odenwald and Schwarzwald, is comparatively simple; the western side of the graben, where it forms the eastern slope of the Vosges, is a compound scarp, in the sense of being determined by several subparallel step faults. The southeastern scarp of the Erzgebirge is of similar origin. The physiographic description of these dissected scarps has not been carried so far as the study of their geological structure. A maturely dissected fault scarp, with a young scarp at its base, forms the eastern slope of the Lepini mountains south of Rome and is described in one of my own papers (**1900**). A number of submaturely or maturely dissected fault scarps are described by Süssmilch (**'10**? 344) as limiting the plateau blocks in the southern tableland of New South Wales. Bell (**'09**) and Cotton (**'12,** 309) describe a dissected fault scarp, with well defined terminal spur facets along the northwest side of Wellington harbor, New Zealand.

Nearly all these accounts of dissected fault scarps are wanting in details as to visible forms; hence if a scheme for the treatment of forms developed on faulted structures were based inductively on descriptions of actual examples now accessible in geographical and geological articles, it would be far from complete. On the other hand, the details as to dissected fault scarp forms already in hand suffice to warrant the establishment of certain general principles from which various consequences may be deduced, as above set forth; and an observer who has these expectable consequences in mind will be prepared to look keenly at the actual features of a faulted district, and to make explicit mention of their significant details in terms suggested by the deductive scheme that he has adopted. It need hardly be said that the scheme must never be allowed to become rigid and controlling; it is simply a means to an end and must be modified and enlarged as experience demands.

OBSEQUENT RAVINE HEADS

In the special cases of small pre-faulting relief and a tilting of the uplifted block surface away from the fault, the initial crest of the fault scarp will form a new initial divide, as in figure 1 B, between the short, steep face of the scarp and the longer back slope of the tilted block, except where antecedent streams maintain their courses across the fault line. But the divide must soon shift away from its initial position by reason of the weathering and retreat of the fault face; the initial divide thus becomes a consequent divide, figure 1 C. The rapid headward erosion of a ravine in a retreating consequent scarp face of this kind will lengthen the ravine stream and correspondingly shorten the opposing back-slope stream; hence the headward part of such a retrogressive ravine, figure 1 D, is then of obsequent origin. Whether any observer cares to go as far as this in applying an explanatory terminology to forms thus developed is not known; but ravines of the kind here indicated are described in Abyssinia by Rathjens (**'11**, 71).

SUBSEQUENT FAULT-LINE VALLEYS

If an example be now considered in which regional uplift accompanies faulting, then the whole surface may be more deeply dissected by its streams and more worn down by weathering and washing than was possible in the cases thus far considered. In such an example the alluvium that at first tends to accumulate rapidly along the scarp base will be removed as the scarp slowly retreats, and the fault line may then be more easily traced, at least by difference of soils even if there is no difference of form. If the rocks on the two sides of the fault line are of similar resistance and the fault is a smooth and simple fissure, no valley need be developed along it even when it is thus laid bare by the removal of the alluvium that for a time covered it; but under other conditions two new features may be developed as follows:

First, let it be supposed that the fault is a complex fissure, along which the rocks are sheared and shattered; then a number of subsequent valleys will be gradually excavated along the sheared zone by the headward erosion of subsequent branches of transverse streams; in time an almost continuous depression may thus come to follow the fault line, and much of its length may by capture come to be drained by the subsequent branches of a few large transverse streams. These valleys are not due to the faulting, and hence should not be called fault valleys; they are the work of headward erosion along the weak structures of the fault line, and hence should be called subsequent fault-line valleys.

Second, let it be supposed that the rocks that are brought together at the base of the fault scarp are of strikingly different resistance, and let those in the uplifted mass be the weaker, as might be the case in figure 1, if we suppose that the lava sheet which there formed the pre-faulting surface lies on weak horizontal strata, such as the sands or clays of a coastal plain or of an aggraded interior basin. As the fault scarp retreats, the weak strata beneath the capping lava sheet will be exposed along a belt, figure 1 E, between the fault-line boundary of the lava sheet in the less uplifted mass and the base of the talus below the retreating lava cliff in the more uplifted mass; a broad subsequent valley will be rapidly excavated along this belt in the manner above indicated for subsequent fault-line valleys. In all such cases the height of the retreating consequent scarp above the valley on the uplifted side will be now measured by the height of the fault *plus* the depth of the valley; and the lower scarp opposite to it, retreating slowly in figure 1 E because the weak strata are little or not at all exposed beneath the lava, will face the uplifted block. Thus two conditions, neither one very complicated, are deduced which must lead to the development of valleys along fault lines; but the valleys are in both cases not consequent but subsequent valleys.

OBSEQUENT FAULT-LINE SCARPS

In figure 1, after the retreat of the heightened consequent fault scarp in the uplifted block, accelerated by the sapping of the weak basal strata, has gone so far as to transform the subsequent fault-line valley into a wide-open lowland, the features of old age are soon locally developed because of the weakness of the rocks on which the erosive processes there work; the other scarp in the lower-lying block may still lie close to the fault line because its retreat is slow. As this scarp is produced by erosion along the fault line and not by the original faulting, and as it has an aspect opposite to that of the initial fault scarp, it may be called an obsequent fault-line scarp. Other examples showing variations on this type will be further considered below.

OLD FORMS ON FAULTED STRUCTURES

In the later stages of a cycle introduced by a fault all the forms of relief will be subdued to mild expression, and eventually an old lowland of erosion—a peneplain or plain, figures 1 F and 2 F—will stretch across the whole district. If subsequent streams were developed along the fault line in the maturity of the cycle, they may now wander away from it in unrestrained meanders. The fault will then have lost all its topographic value, though it may still be visible in a difference of soils on its two sides. Hence the scarp of a physiographically "old" fault has not only retreated from the fault line, but has been topographically obliterated; yet the fault, geologically considered, still remains unchanged. Its slip, strike, hade, and other elements are not altered, although its physiographic expression has passed from its initial stage through all its sequential stages in the cycle of erosion introduced by the faulting to its ultimate disappearance. Evidently, then, the physiographic treatment of faults must be very different from their geological treatment.

During all the late stages of the cycle, after the pre-faulting forms have been destroyed, there is no longer any need or indeed any possibility of saying anything about them; they have vanished. Nor is the slip of the fault or the height of the initial scarp at this time of physiographic importance. Here and there some gentle fault-line slopes, maintained on resistant rocks, bordering or inclosing a broadly opened fault-line depression, may survive; but eventually only the location and direction of the fault line as a limit between unlike soils need be noted in a physiographic description.

Here we find a further application of the general principles of physiographic description, to which attention has already been drawn. At the beginning of a cycle introduced by faulting, the pre-faulting forms and the fault forms must be described; in the early and mature stages of the cycle the post-faulting forms must be added; now, in the late stages of the cycle, the two first elements may be passed in silence, for nothing is known of them; the post-faulting forms everywhere prevail and these alone need mention. The fault is topographically obliterated, and is of value physiographically only in delimiting different soil areas, yet it is geologically of the same value as when it was first produced.

Transverse Faults in monoclinal Structures

A case of special interest is furnished by monoclinal structures of alternating strong and weak strata, which before faulting have been reduced to rather small relief, so as to present a series of low, rectilinear, subsequent ridges and valleys. Assume that the monoclinal dip is 20° to the northwest, and that the district is then broken by a transverse fault, with vertical uplift on the northeast, as in figure 4 A. The initial position of the ridges and valleys in the uplifted block will be changed only in altitude, but not in latitude or longitude. The linear continuity of the ridges and valleys will not at first be affected in plan; but as the new cycle advances, the ridges and valleys in the uplifted block will be shifted down the dip of their determining strata (except that under special conditions of small dip and moderate contrast of resistance a strong subsequent stream may cut down its new valley vertically, and thus come to be structurally superposed in a resistant stratum), and near the close of the cycle all the members on one side of the fault line will be laterally displaced, or "offset," from their fellows on the other side, as in figure 4 B, thus giving the effect of a fault of horizontal slip. Sometimes the offset may bring the halves of different ridges together; the fault line between them may then be marked by a mere notch or by a transverse valley. More frequently the offset will result in a haphazard opposition of a longitudinal valley to a truncated ridge. Special features will be determined by the angle between the strike of the monocline and of the fault line, which I have elsewhere treated ('89, '98).

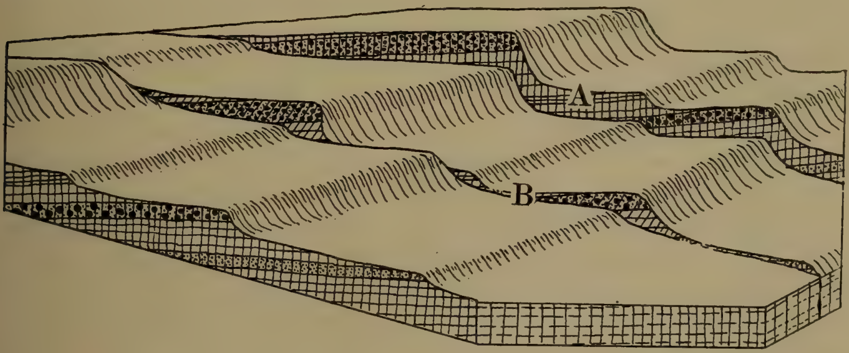


FIGURE 4.—*Transverse Faults in a monoclinal Structure*

SECOND-CYCLE FORMS ON FAULTED STRUCTURES

Now suppose another cycle of erosion to be introduced by a broad uplift of the whole region without renewal of faulting. This may happen at any stage of the interrupted cycle, but we will here consider only interruptions that occur near the end of the cycle that they interrupt. The streams of the region will be revived by the new uplift. The shattered rocks of any shear zone and the areas where weak rocks are exposed will waste away rapidly and will soon be reduced to new valleys and lowlands; the harder parts of the broadly uplifted area will for a time retain nearly the altitude of uplift except where cut down by streams. In other words, the weak parts grow old rapidly, while the resistant parts pass through their cycle of development slowly; hence in a carefully stated description terms indicative of age must be separately applied to areas of different resistance. This is the converse of another principle, namely, that strong agents of erosion, like large rivers and strong sea waves, run through their cycle of form development rapidly, while weak agents, like weathering, advance slowly; hence the valleys of large rivers will reach late maturity or old age while the surface of neighboring interfluves are still young or submature.

If it happens that the rocks on one side of the fault are resistant and on the other side weak, a scarp will be developed along the fault line on the side where the resistant rocks retain young or submature forms, and this scarp will face the worn-down area, where the weak rocks are already subdued or old. The aspect of such a scarp is evidently independent of whether the resistant rocks are in the block of relative uplift or depression. If the newly developed scarp faces the originally uplifted mass, as in figure 1 G, it may be called an obsequent fault-line scarp, as already defined; if it faces the originally depressed mass it may be called a resequent fault-line scarp, because it again faces in the direction of the original scarp. Both kinds of fault-line scarps are drawn in figure 2 G. In the case of a faulted monocline, as drawn in figure 4 B, obsequent and resequent ridge-end scarps will alternate, right and left, along the fault line.

The distinction between fault scarps and fault-line scarps, in the manner here proposed, is not simply an academic question of systematic nomenclature. If a fault-line scarp is taken for a fault scarp, various erroneous inferences will follow; for example, the date of faulting will in such a case be inferred to be only long enough ago to permit the observed dissection of the scarp; while if properly interpreted the date of faulting would be at any period prior to the erosion of the preceding cycle, and hence possibly much more ancient than at first supposed. Further, the height of a young or submature fault scarp is a fair measure of the faulting, while the height of a fault-line scarp has no close relation to the faulting; it is dependent simply on the depth to which renewed erosion has brought about a different altitude on the two sides of the fault line; hence if a fault-line scarp is mistaken for a fault scarp, the height of the scarp may be mistaken for the vertical separation produced by faulting, thus giving incorrect measure of the original separation. In an early stage of the new cycle the fault-line scarp will be highest near the incised valleys of transverse streams, and it may remain for a time undeveloped on the interfluves; a variation of scarp height thus systematically connected with surface streams must evidently be due to stream action and not to the original movement of the fault. Further, it should be noted that in an advanced stage of second-cycle erosion on a mass of complicated structure, newly developed fault-line scarps must be discontinuously developed, according to the opportunity that the weaker structures offer; they must always rise on the side of the more resistant rocks and overlook the area of weaker rocks; they must therefore here be of resequent, there of obsequent aspect, as in the cases of figures 2 G and 4 B, above referred to. Evidently so systematic a relation of scarp aspect to rock resistance must be the result of erosion, not of faulting; hence if a fault-line scarp were mistaken for a fault scarp, the uplift might be thought to be on the wrong side of the fault line.

In a second cycle, fault-line valleys will be developed by the action either of revived consequent streams or of subsequent streams working along the shattered zone of a fault bordered on both sides by rocks of significant resistance. Thus we see once more that, as far as valleys following fault lines are concerned, they may be developed either by revived or by new subsequent streams in a second cycle, succeeding any advanced stage of the cycle introduced by faulting. If the rare occurrence of consequent fault valleys as above set forth is now recalled, it will appear that most valleys associated with faults are likely to be of subsequent origin. They are not due directly to faulting alone, but to erosion working on a faulted structure. They are not initiated by the faulting movement, but first take the form of valleys long after the faulting has ceased. Hence they should be called by some special name, such as fault-line valleys, as here suggested, and the term fault valleys should be limited to valleys produced by erosion closely consequent on faulting.

Fault-line scarps in the early stages of a second cycle following an advanced stage of a previous cycle, and traversing a district of gently inclined strong and weak strata, will be associated with a peculiar and significant arrangement of ridges or of cuestas that deserves special mention. The advanced erosion of the first cycle will have resulted in producing offsets in corresponding ridges or cuestas, so that their ends will abut against the fault line some distance apart, as in figure 4 B. If old age be reached, the soil belts will be offset along the fault line. When renewed erosion of the weaker strata in the second cycle, introduced by uplift without renewed faulting, develops discontinuous fault-line scarps close along the fault line, their small retreat might be taken—especially by observers who are not critical in distinguishing fault-line scarps from fault scarps—to mean that the fault is of recent date; but the strong offsets of the corresponding ridges or cuestas will contradict this view and prove that the scarps are due to erosion after renewed uplift of a faulted and previously worn-down structure, and not directly to faulting. If the scarps were due to recent faulting, the corresponding cuestas ought still to stand nearly opposite each other on the two sides of the fault line. But this interpretation of the case has a geological flavor, in that it turns the attention chiefly to a succession of past events. A more geographical interpretation is reached when the mere mention of scarps in such a structure as fault-line scarps, either resequent or obsequent, at once awakens attention to the probable strong offset of corresponding reliefs on the opposite sides of the fault line.

As long as any significant traces of the forms developed in a first cycle are not obliterated by the erosion of a second cycle, they deserve explicit description in a physiographic discussion, following the general principle above stated; and their description should introduce, in any fitting order, a sufficient account of the faulted structure on which the forms of the previous cycle were developed, the processes that developed them, and the stage of development that they had reached when further progress was interrupted by uplift; then the effect or amount of the uplift should be stated, and finally the forms developed in the new cycle should be introduced in their proper relation to the surviving forms of the previous cycle. The omission of any one of these factors will leave the reader in doubt as to what the writer has seen.

With the advance of the new cycle even the hard-rock uplands will in time be maturely dissected, then subdued, and at last worn down to small relief in advancing old age; with these changes the newly developed scarps will retreat and take on details of form according to the structures revealed in them, after the fashion of retreating escarpments of whatever origin; thus the fault will again be topographically obliterated in the resulting lowland. The forms of earlier cycle thus lose their importance and do not need mention after the maturity of the new cycle. Eventually the uplands, hills, and scarps must all fade away, and a widespread lowland, figures 1 H and 2 H, will stretch across the region. Then or at any earlier stage uplift without faulting may again occur and the systematic series of changes will be begun over again; yet during all these physiographic transformations the fault is, geologically speaking, a constant quantity. Or renewed faulting and differential uplift may take place along the former fault line, and thus introduce more complex problems. Examples of this kind have been described by Huntington and Goldthwait ('04, 225) and by D. W. Johnson ('09, 154).

Most faulted structures are today probably in a later cycle of erosion than the one introduced by the faulting. Hence although the space here devoted to the forms developed in later cycles is less than that given to the forms of the cycle introduced by faulting, the use of the terms chiefly associated with later cycles, such as obsequent and resequent fault-line scarps and subsequent fault-line valleys, ought probably to be more frequent than that of terms associated with the cycle of faulting, such as fault valleys, consequent scarps, and so on.

Examples of second-cycle Forms on faulted Structures

An admirable example of a submaturely dissected resequent fault scarp is found where westward ascent is made from the broad plains of the Limagne to the crystalline highlands of Auvergne in central France. The scarp might well be taken, at first sight, to be consequent on faulting; but a study of the lava-flows that cross it and their relation to the lacustrine strata that once filled the Limagne graben will prove its resequent origin. An equally good example is found in the western part of the same crystalline highland, known as the Limousin, where it suddenly descends southwestward into the basin of Brives, that has been excavated on weak strata which were brought down against the crystallines by strong faulting, as described by Demangeon (**'10**). A third example, this time of a maturely dissected obsequent scarp, is found in the ascent on the northeast side of the excavated subsequent depression in northwest France, known as the Pays de Bray, of which the geological history has been studied out by Lapparent (**'79**, 113–). The renewed erosion in the second and third of these examples followed a late stage of an earlier cycle at the beginning of or before which the faulting took place.

A remarkable group of escarpments following a series of east-west faults occurs in central Sweden and is finely represented on the 1 : 100,000 map of that country, sheets 55, 56, 65, 66, 73, 74. These escarpments have been regarded as what are here called submature consequent fault scarps by Gunnar Anderson (**'03**, 27-49) and S. De Geer (**'10**, 34), but are to my view (**'12**, 169) better explained as submature resequent fault-line scarps developed in a second cycle, following the old age of a previous cycle; many subsequent fault-line valleys are associated with them. On the other hand, Brögger (**'86**) has described some mature scarps in the Christiania district which face the uplifted side of their fault-lines and which would therefore here be called obsequent. They are probably due to erosion in a later cycle of erosion than the one introduced by faulting.

In Scotland the abrupt southward descent from the crystalline highlands to the worn-down stratified rocks of the central lowlands is made by what seems to be a maturely dissected and strongly glaciated resequent fault-line scarp, developed in a second cycle by renewed erosion on a previously faulted and subdued mass. The long scarp on the northwest side of Newfoundland, above mentioned as thought by Twenhofel to be a fault-scarp, is possibly—or probably—a fault-line scarp.

Several submature resequent fault-line scarps with eastward aspect are crossed by the Mohawk valley in eastern New York, and have received general study from Darton (**'95**). The scarp at Little Falls has been described in detail by Cushing (**'05,** 71–); others of diverse aspect farther east near Saratoga by Miller (**'11,** 38–). A long and strong resequent scarp, with southeastward aspect, forms the border of the crystalline highlands toward the red sandstone lowlands in northern New Jersey; it is described by Kümmel (**'98,** 110) as a geological boundary rather than as a topographical feature. The eastern border of the Connecticut valley lowlands in Connecticut and Massachusetts is a west-facing scarp of the same nature, but more irregular in plan; it was worked out by Griswold and is described in my report on the Triassic formation of that district (**'98,** 122); the trap ridges of the same lowland in Connecticut are repeatedly terminated by oblique resequent or obsequent fault-line scarps, often too young to have their slopes completely graded, while in the already old, worn-down areas of weak sandstones the same faults are nearly or wholly obliterated (**'89,** 68; **'98,** 89). A remarkably good example of a maturely dissected obsequent scarp, now worn a mile or more back from its fault line, runs transverse to the dominating structural trends across the boundary between the Appalachian ridges and the Cumberland plateau in northern Tennessee; it is well represented on the Briceville folio of the United States Geological Survey. Several other obsequent fault-line scarps have lately been described by Paige for central Texas in the Llano-Burnet folio. Subsequent fault-line valleys and obliterated fault scarps are repeatedly illustrated in the Appalachians of Virginia and Tennessee.

The Hurricane ledge in the plateaus of northern Arizona north of the Colorado canyon is an exceptionally fine young, west-facing resequent fault-line scarp; it was described as a young fault scarp by Dutton (**'85,** 112–), but its resequent nature seems to be well established by a lava flow that I found in 1902 to lie across the line of the obliterated scarp of first faulting, protecting a local area of weak clays which have elsewhere been worn away on the west of the fault line, leaving the resistant limestones in bold relief on the east side (*a,* **'03,** 26–; **'12,** 171).

A neighboring fault, studied by D. W. Johnson ('09, 148) and myself ('01, 142), was found to be topographically obliterated for much of its length, but it appears locally in obsequent and resequent scarps transversely truncating several cuesta-like benches in the northward ascent from the Arizona plateaus to the High plateaus of Utah.

There can be little question that the recognition of the possible origin of scarps along fault lines by erosion (fault-line scarps) as well as of scarps by faulting (fault scarps) aids the determination of the class to which a scarp belongs. The possession of an elaborated mental equipment, including a good variety of type forms associated with faulted structures, facilitates the detection of corresponding actual forms in the field. The cases here considered, therefore, have a practical value as part of the mental outfit of every observant student of land forms.

An imaginary Example

It is probably because of the unchanging constancy of the geological elements of a fault that many descriptions of faulted districts made by geological explorers are physiographically so unsatisfying. Indeed, one sometimes reads even in geographical journals and under headings that indicate the intention of the writer, whether he be a geologist or geographer, to produce a description of a landscape that he has traversed, such a statement as the following: An important fault, with a displacement of about a thousand feet, here brings Archean rocks and Triassic beds against late Cretaceous strata. The failure to mention the strike of the fault and the side of relative uplift is unsatisfactory even from a geological standpoint, although the introduction of such terms as Archean, Triassic, and Cretaceous may give a geological reader some consolation for other shortcomings. But the geographer is left entirely adrift by such a description, particularly if it is not accompanied by an appropriate map or diagram; he can form no definite mental picture of the landscape seen by the writer. The age of the faulted beds is of no use to him, although it is unfortunately becoming habitual, especially in Germany, to overload geographical descriptions with terms expressive of geological dates. Such terms are, of course, of value in themselves; they are useful in various scientific relations; they are essential in a geological history of a district; but, let it be repeated, they give no aid in forming a mental picture of surface forms; hence they are of no value in a purely geographical description. What a geographical reader does need to know as to the rocks, in such an instance as is here considered, is not the ancient date of their formation, but their present composition, attitude, and relative resistance; and as to the fault, the stage of erosion that has been reached with respect to it in whatever cycles of erosion that have left visible traces; also whether the fault line is marked by scarps or valleys, and if so of what kind, and so on. A more satisfying physiographic description of the district here imagined might therefore be phrased as follows:

An important fault line, trending about northeast-southwest, separates a northwestern body of massive crystalline rocks, evenly covered by an alternating series of hard red sandstones and weak shales, dipping southwestward about 30°, from a southeastern body of younger, nearly horizontal, weak, gray sandstones and marls. The rolling uplands of crystalline rocks in the northwestern part of the district are irregularly dissected by rather close-spaced, early mature valleys, of which the larger ones, 250 or 300 feet in depth, trend southwestward as if eroded by superposed streams that were originally consequent on a former sandstone cover, while the smaller ones are for the most part of insequent habit. The red sandstone ridges rise 200 or 300 feet over the broad, late mature subsequent valleys that follow the intercalated shale belts; here the drainage is well adjusted to the structure. The gently rolling surface of the crystalline uplands and the even crestlines of the sandstone ridges, taken with the equable altitude of two east-west dikes, one of which crosses the fault line, suggest that, since the tilting and faulting, the whole district has been eroded to a peneplain, again broadly uplifted sev-

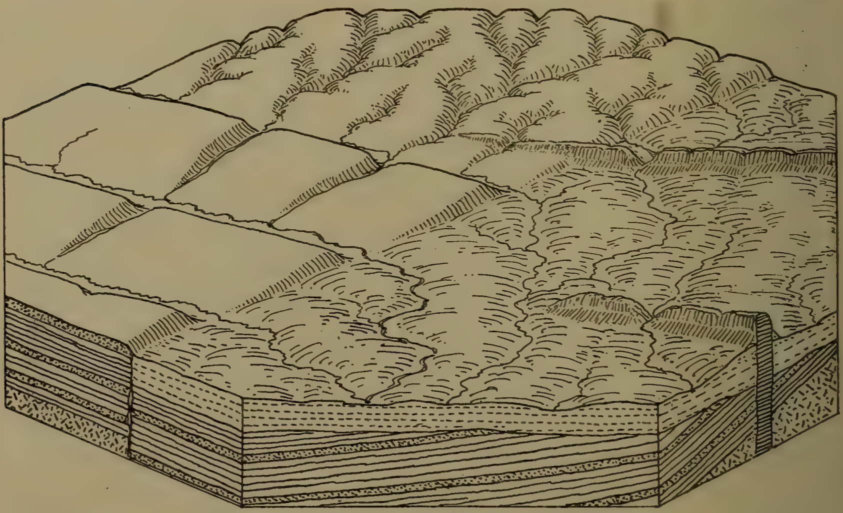


FIGURE 5.—*An imaginary Example of a resequent Fault-line Scarp*

eral hundred feet without faulting, and thereupon again eroded; the northwestern district being now in early or late mature stages of the cycle thus introduced, while all the southeastern district of weaker sandstones has reached a late mature or almost old stage, as indicated by its low, subdued hills, separated by broad-floored, wide-spaced, shallow valleys of typically insequent pattern; and the fault boundary between the two districts being marked by a dissected resequent fault-line scarp along the border of the crystalline uplands and by a series of resequent fault-line scarps facing southeast and obliquely truncating the sandstone ridges; but the fault is topographically obliterated where the subsequent shale valleys open on the southeastern lowland. If such a description be accompanied by a diagram, like figure 5, the essential features of the district concerned may be easily conceived.

The essence of this imagined physiographic description is that it attempts to introduce everything that is relevant and nothing that is irrelevant to a clear comprehension of the surface features in the district concerned. The names of geological formations are intentionally omitted, because they do not aid in conceiving the visible landscape; but if the physiographical description were intended as an introduction to a geological report, geological formation names might, of course, be mentioned at the outset. The attitude of the strata, often regarded as a purely geological matter by geographers of the empirical school, is really a very serviceable physiographic factor, because it enables the reader easily to conceive certain systematically associated features which would otherwise have to be described one by one. The fault, the two cycles of erosion that have followed it, and the uplift without faulting that separated them are all manifestly of service in leading the reader to picture what the writer has seen; but these factors, like all others relating to past conditions and events, are not introduced with the object of narrating the history of the district—that would be pure geology—but with the object of setting forth its present form, and that is proper physiography.

Forms produced on faulted Structures by other than normal Processes

All the foregoing discussion has been under the postulated action of normal erosional processes—that is, weather and running water. The other chief processes—solvent action of water, waves and currents; glaciers, and wind—also deserve treatment in their proper place; but such treatment may for the present be postponed until more examples of faulted structures acted on by these various processes come to be known.

One might easily deduce, from what is already understood of the action of sea waves on coasts of different kinds, a series of ideal types dependent on faulted coastal structures—for example, the development of fault-line chasms by the attack of the sea on the weak breccia of a sheared fault; or the more rapid advance of the marine cycle on a body of weak rocks alongside of its less rapid advance on a neighboring body of hard rocks, the two rock masses having been brought together by a fault, reduced to subdued forms, and then submitted to marine action by depression. Similarly, a valley glacier, while actively overdeepening its trough, might develop a more or less abrupt step in the trough floor on passing across a fault from a resistant to a weak rock body; or a basin, on passing from a weak to a resistant rock body; likewise, the trough walls might be well smoothed or matured in less resistant rocks, while they still retained ragged or youthful features in more resistant rocks, as appears to me to be the case in certain glaciated troughs of the Snowdon district in Wales, although the juxtaposition of the two rock masses was not, as far as I know, in that case brought about by faulting. The fuller discussion of these and many other examples may wait till it is wanted.

In all these cases the object in view and the principles to be observed in reaching it remain the same. The object is the explanatory description of the visible landscape as directly as possible, with no more of past geological history than is helpful in attaining this object. The principles already illustrated regarding the description of the pre-faulting forms, of the direct effects of faulting, and of the post-faulting forms may be expanded so as to include the description of forms developed under the action of different processes, as has already been implied in the mention of coastal forms in earlier paragraphs. For example, when one process is replaced by another, the description of the resulting forms should include the forms reached under the first process at the time of change, then the change of process, and lastly the forms developed by the new process as modifications of the previous forms. In brief: here, as in all other cases, let the physiographer answer the question, "What does it look like?" in terms of the visible products of the work of processes on structures; and his work will be accomplished.

DEFINITIONS OF TERMS USED IN DESCRIBING FORMS ON FAULTED STRUCTURES

It may now be better understood than at the beginning of this paper why the nomenclature of surface forms produced by the erosion of faulted structures—that is, the physiographic nomenclature of faults—was not introduced by definitions of a geometrical kind. Such definitions might be framed, but they would not meet the object desired, which is to describe the fault forms in their natural association with neighboring forms, all treated in relation to the stage of their development in one or more cycles of erosion, following some appropriate and systematic scheme of general application, the scheme here adopted being that of "structure, process, and stage." It is impossible to apprehend this manner of describing fault forms merely from definitions of terms; but after the manner of description has been learned, as from the foregoing discussion, it would be an easy matter to define all the terms regarding such forms in compact statements, which might be easily carried in mind after their useful meaning has been apprehended. Any one may make these definitions if he wishes to. I have refrained from so doing, even at the end of this essay, for fear that some readers might use the definitions as a short cut to a supposed understanding of the problems involved, and thus place the cart before the horse, the terms before their need and their meaning.

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POSTGLACIAL EARTH-MOVEMENTS ABOUT LAKE ONTARIO AND THE SAINT LAWRENCE RIVER[1]

BY J. W. SPENCER

(Read before the Society December 31, 1912)

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INTRODUCTION

The maximum amount of deformation and direction of the postglacial earth-movements was first discussed by me in a memoir entitled "The Iroquois Beach: a chapter in the geological history of Lake Ontario."[2] In this I made the following statement:

"If the axes of maximum elevation for the various triangles about Lake Ontario and Georgian Bay be produced, they meet near latitude 51° north and longitude 74½° west, a few miles west of Lake Mistassini, and east of the southern end of James Bay.

"Although mainly radiating from the focus, the axes of maximum elevation for the different triangles is not uniform, and are locally modified, as along the western side of Lake Ontario, where there is found a secondary axis of uplift to the east. Combining the more western axes with those of the eastern end of the lake, another focus of uplift appears near the 'height of land' between Lake Ontario and Hudson Bay, in about latitude 48° north and longitude 76° west. From the double foci, it may be inferred that the uplift reached its maximum along a line joining the foci, or that the axis of the maximum regional uplift was meridional and located along the eastern end of Lake Ontario, increasing in amount until near 'the height of land,' and thence with a diminishing ratio, or even depression, toward the north. Still it is hardly probable that the increasing ratio is constant, as there are local transverse folds on both sides of the Ontario basin. At any rate, it is in the region southeast of James Bay that the maximum differential elevation of the earth's crust, which involved the Iroquois Beach, is to be found."

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[1] Manuscript received by the Secretary of the Society March 3, 1913.

[2] Trans. Royal Society of Canada, vol. vii, sec. iv, p. 129; read May 5, 1889. See also Journal of Geology, vol. xix, 1911, pp. 57-60.

While this was written in the pioneering days of our lake studies, it has nevertheless been the key to subsequent researches. Since then Gilbert, De Geer, Taylor, Leverett, and, more completely, Goldthwait, have shown the deformation by isobars in place of my triangles, which last method has been used by Coleman. Goldthwait's extension of the isobars westward to Lake Algonquin is an admirable addition to the subject, which stimulates further research. Each method has its advantages. The isobars show the lines of equal rise, while the triangles give the mean rate of deformation in different localities, and in addition they suggest the amount of change beyond the points where measurable data are found. The deformation is now determined eastward nearly to Lake Champlain and Montreal.

IROQUOIS WATER NORTH OF THE ADIRONDACKS

In my original surveys of the Iroquois Beach, the shoreline was traced to a point 4 miles east of Watertown, New York, beyond which the beach was interrupted in the broken country. To this point all of my determinations of elevation were made by leveling. To the eastward, fragments of beaches were found, the elevations of which were determined by the aneroid, as at Natural Bridge, Pitcairn, and Fine. Although their positions appeared rather high, I regarded them as the equivalent of the Iroquois shore, thus making the eastern rise seem excessive; but they indicated open water north of the Adirondacks. This was one of the features which caused me to oppose the hypothesis of glacial dams. Such dams had been located by the advocates of the hypothesis at Cleveland, Adams Center, and Crittenden, but the further survey of the beaches showed that they continued beyond these points, which thus cast additional doubt on the theory. Another objection was presented by the fact that glacial lakes would not remain long at one level, with the water of large streams flowing across ice-barriers; but this objection has been partly overcome by the finding of other spillways passing through rock or earth-bound channels in place of across icy barriers.

Although the beaches had been found east of Watertown, as at Pitcairn, Professor Fairchild drew a glacial dam, as presented on his map,[3] right over them, but later he has abandoned this theory, and finds that the Iroquois Beach continues farther eastward.[4] Thus he confirms my early hypothesis of open water north of the Adirondacks, although one time I regarded it as marine.

On personally making the investigation of the Mohawk outlet of Lake Iroquois, the terraces were observed higher than its water plane. This fact threw a new light on the shorelines north of the Adirondacks, and seemed to justify the correlation of the beaches and terraces occurring there with those of the Mohawk, as well as indicating that there were also lower ones corresponding to the Iroquois level. I then zigzagged at proper elevations and found the repetition of the terraces or beaches extending to the northeastern angle of the Adirondacks plateau. The marine deposits were also studied. All the measurements bearing on the deformation have been triangulated, with the results that shorelines of the region of northern New York and beyond the Saint Lawrence are now explainable in a manner not previously understood.

Iroquois Shore and higher Terraces in the Mohawk Valley

Southeast of Lake Ontario, the Iroquois Beach sweeps around an embayment now well known as the Rome outlet of Lake Iroquois. An outlet of the Ontario basin along this route was mentioned by Professor Newberry[5] as early as 1871, if not before. This was long prior to the first investigation of Lake Iroquois.

At Rome the embayment is 2 or 3 miles wide, with the floor covered by the delta deposits brought down by the Upper Mohawk. This gradually narrows to a valley, which is still a mile wide at Herkimer, 27 miles distant in a direct line, and 12 miles south of the latitude of Rome. Six miles farther east, at Little Falls, the valley contracts to little more than a quarter of a mile, and here the river passes through a rock-walled channel; but a mile and a half below the valley abruptly broadens out. At Little Falls the rapids descend 40 feet over an ancient rocky divide between two preglacial valleys, now deeply filled with drift, including interglacial clays, which are covered with the shore and delta deposits of Lake Iroquois. The modern Mohawk River, below Rome, appears to be flowing contrariwise to the direction of the ancient rock-bound valley, but in doing so it is simply coursing its way over the plains and delta accumulations of this eastern arm of Lake Iroquois. These have an elevation of 445 feet above sealevel at Rome and 406 feet at Herkimer and at Mohawk, with remnants of the same gravel deposits at Little Falls, which is nearly in the same latitude. These observations furnish data for determining the earth-movements farther southeastward, showing that this locality is beyond the axis of postglacial elevation, and that the apparent warping here is downward.

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[3] Twentieth Ann. Rept. State Geological Survey of New York, 1902.

[4] New York State Museum Bulletin No. 158, 1912, pp. 32-35.

[5] Geology of Ohio, 1871.

A higher terrace of the Mohawk is of great importance. East of Herkimer the front of this gravel deposit, resting on clay, rises some 90 to 110 feet above the Iroquois plane. A similar elevation of the terrace is repeated some 4 miles north of Rome and elsewhere. This higher water plane is older than that of Lake Iroquois, and requires further investigation, but it throws suggestions on the shorelines north of the Adirondacks.

North of the Mohawk Valley other terraces occur at still higher elevations. Thus one of great magnitude may be seen northwest of Trenton Falls, on the road to Prospect, at 260 feet above the broad valley, or between 1,010 and 1,030 feet above tide, with the plains at Prospect at 1,170 feet. These all face the south, showing open water in that direction; but only the lower terraces need to be mentioned here.

Features of the Country North of the Adirondacks

The ancient preglacial surface of the country, descending some 2,000 feet northward from the Adirondack plateau, was deeply dissected by broad valleys, now covered with a mantle of drift, yet these have still a depth of from 50 to 300 feet. In them terraces, deltas, and broad plains of sand and gravel occur, both near the levels of the streams and at higher elevations. Consequently all the old shorelines north of the Adirondacks have been much interrupted by the former estuaries, so that the observation must now be made, sometimes on the beach ridges or again on the corresponding terraces or deltas. Generally there are no topographic maps of this region to give even imperfect assistance in following the shorelines which rise from one contour to another. Such features make the identification of a particular strand somewhat difficult, unless continuously followed and the elevations determined by the spirit-level. This method was used by me to a point 4 miles east of Watertown, while beyond the measurements were by aneroid. This instrument originally indicated that the beach near Stirling Bush was too low, which led to the finding of the higher strands at Natural Bridge and at Fine, which are now seen to be above the Iroquois plane, while the measurements of the corresponding ridge road at Pitcairn was excessive in height.

In his recent report,[6] Prof. H. L. Fairchild has extended my investigations beyond Watertown, but he gives only one observed measurement (at Parishville) on the Iroquois Beach within a distance of 125 miles, although the features of the country are so very complex. At this one point we agree in recognizing the Iroquois plane, but not in its occurrence at Covey Hill, as will be shown.

TRIANGULATION OF EARTH-MOVEMENTS RECORDED IN THE BEACHES

The location of the Iroquois Beach is now well known to a point east of Watertown, and its elevation at several points suitable for triangulation measurements is given in the following table; also the approximate location of the same beach northeast of Watertown is indicated as far as Covey Hill, at the northeast angle of the Adirondack plateau. East of Parishville the general course of the beach is in a direct line approximately east-northeast, so that beyond this point its direction does not permit of triangulation measurements.

The elevation of the Iroquois Beach at or near places mentioned is given in feet above sealevel, so that the earth-movements can be determined from them. When not otherwise stated, my elevations were determined by the spirit-level.

Table of Elevations

Hamilton	363 (Spencer).
Scarboro	456 (Spencer).
Colborne	502 (Spencer).
Trenton	633 (Spencer).
Lewiston	384 (Spencer).
Rochester, West of	435 (Fairchild).
Sodus	456 (Fairchild).
Rome	445 (railway).
Herkimer	406 (railway).
Little Falls, Near	400 (barometer).
Richland	563 (Gilbert).
Adams Center	657 (Gilbert).
Watertown	730 (Spencer).
Stirling Bush, North of	770 (barometer).
East Pitcairn	832 (barometer).
South Edwards, gravel terrace	800 (barometer).
Silver Creek, Near	865 (barometer).
Parishville	903 (railway).[7]
Malone, East of	930 (barometer).
Covey Hill (upper lake)	915 (barometer, close reading).

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[6] New York State Museum Bulletin No. 158, 1912, pp. 32-35.

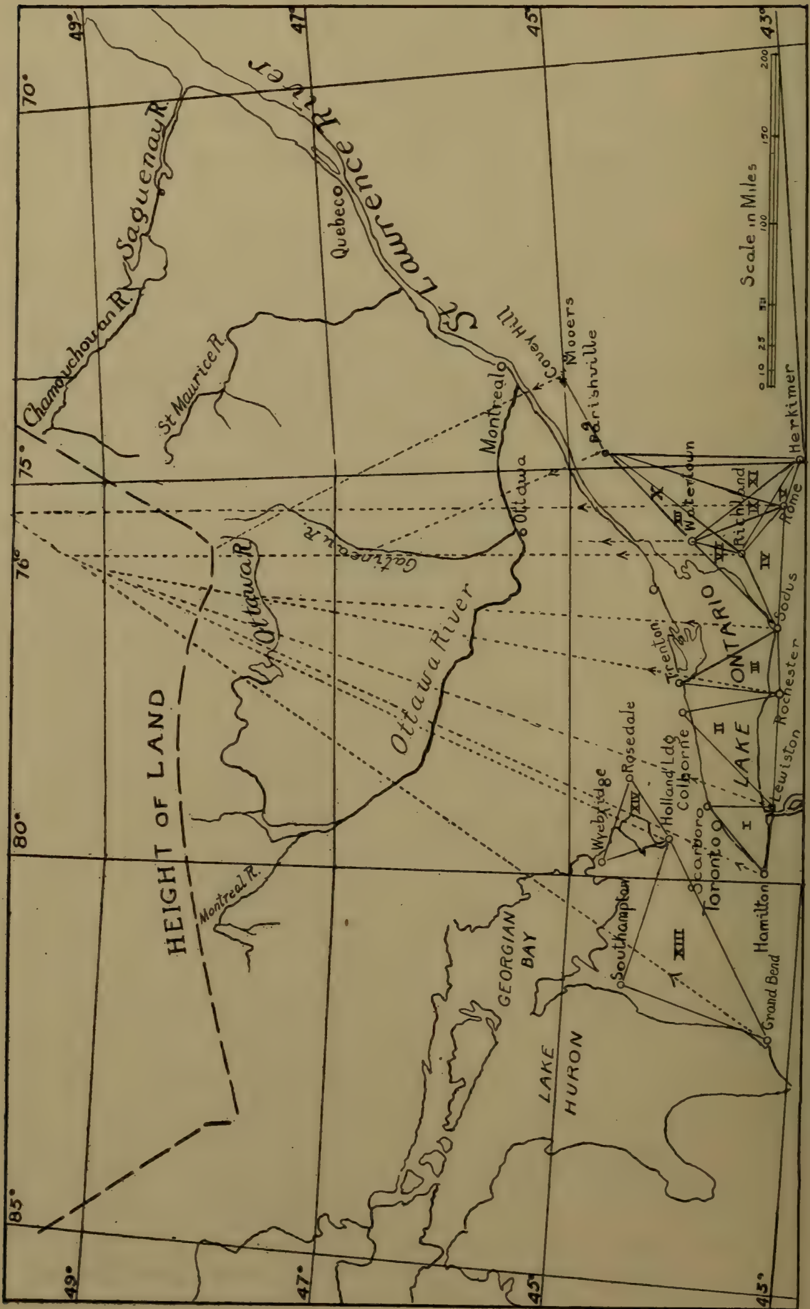
70°
75°
76°
80°
85°
49°
47°
45°
43°
St Lawrence River
Saguenay R.
Chamouchouan R.
St Maurice R.
Quebec
Montreal
Covey Hill
Mooers
Parishville
Ottawa
Gatineau R.
Ottawa R.
Ottawa River
Montreal R.
HEIGHT OF LAND
Herkimer
Watertown
Richland
Rome
Sodus
Rochester
Lewiston
Trenton
LAKE ONTARIO
Colborne
Holland Ldg
Rosedale
Wyebridge
Scarboro
Toronto
Hamilton
Southampton
Grand Bend
GEORGIAN BAY
LAKE HURON
I
II
III
IV
V
VI
VII
IX
X
XI
XIII
XIV
Scale in Miles
0 10 25 50 100 150 200

FIGURE 1.—*Map of the Triangulation of Deformation measured in the Iroquois and Algonquin Beaches*

Height of Algonquin Beach Southeast of Lake Huron

Grand Bend	602	(Spencer).
Southampton	714	(Spencer).
Weybridge	842	(Spencer).
Holland Landing	752	(Goldthwait).
Rosedale	891	(Goldthwait).
Kirkfield	875	(Spencer).

In the following triangles the mean direction and rate of deformation in feet per mile have been calculated to be:

1.	Hamilton, Lewiston, Scarboro	2	feet,	N. 22° E.
2.	Lewiston, Rochester, Colborne, Ontario	2.5	“	N. 17° E.
3.	Rochester, Sodus, Trenton	3.6	“	N. 10° E.
4.	Sodus, Rome, Richland	5	“	N. 4° E.
5.	Rome, Herkimer, Richland	4.5	“	N.
6.	Sodus, Herkimer, Watertown	5.5	“	N. 2° E.
7.	Richland north toward Watertown	6	“	N.
8.	Adams Center north toward Watertown	6	“	N.
9.	Rome, Herkimer, Watertown	5:1	“	N., 2°
10.	Rome, Watertown, Parishville	5.5	“	N. 22° W.
11.	Rome, Herkimer, Parishville	4.4	“	N.
12.	Richland, Watertown, Parishville	6	“	N. 23° W.
13.	Grand Bend, Southampton, and Rosedale	1.3	“	N. 35° E.
14.	Holland Landing, Wyebridge, and Rosedale	3.4	“	N. 23° E.
15.	Bradford, Owen Sound, Wyebridge	3.1	“	N. 27° E.
16.	Adjacent to Kirkville	5	“	N.

By plotting these lines of direction on the map, those drawn from the lowest points of the triangles converge to a focus near latitude 49° north, longitude 76° west, while those drawn from the more eastern points of the triangle will be seen to converge at points beyond the first focus, as far as latitude 50° 30′, longitude 75° west. These points are, consequently, the foci of maximum uplifts as determined more than twenty years ago.

It is interesting to find that certain physiographic features confirm these computations, for near this dome rivers are found radiating in different directions in conformity with the hypothesis. Thus we find the source of the Ottawa River is near one of the foci, from which it flows westward for nearly 200 miles parallel to the "height of land" before turning southward, as shown on the map. The Gatineau and Saint Maurice rivers flow southward from the same district, while the upper waters of the Chamouchouan flow northeastward from the same region,

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[7] 520 feet, according to Fairchild.

parallel to the "height of land" for 60 miles, before turning southward to Lake Saint John.

The deformation extending to the "height of land" is further shown by the Montreal River, flowing 60 miles northward, before being turned abruptly southward (Bell).

By referring to the map, it is seen that the axis of the Laurentian Mountain plateau, after trending southwestward from Labrador, turns abruptly westward, and farther on again bends to the northeastward. Thus the region of the greatest deformation coincides with the most southern lobe of the Laurentian plateau.

From the data given in my Niagara book and earlier papers, it will be seen that there is very little deformation about the head of Lake Erie. This increases, so that the rise about the head of Lake Ontario is 2 feet per mile in direction north 22° east. Beyond the outlet of Lake Ontario the eastern equivalent in the rise disappears, but, as in the Mohawk Valley, the tilting is 3 or 4 feet per mile in a northward direction. This increases to 5 or 6 feet per mile on proceeding toward the Saint Lawrence River.

Passing this meridian (longitude 76° west) of exclusive northward deformation, the direction of the warping is north 23° west, reaching 6 feet per mile, as in triangle number 12, which extends to Parishville. Consequently the isobar of this elevation trends north 67° east. The isobars of any height can be located in the various triangles by drawing lines through the points of equal deformation at right angle to the direction of mean rise in each triangle.

The direction of the earth-movements is thus seen to bend, after passing Watertown, in conformity with the change in the course of the "height of land," east of the 76th meridian. This observation is further shown in the next paragraph.

IROQUOIS PLANE IN THE REGION OF COVEY HILL

If the isobar of Parishville (903 feet) be produced, its course of north 67° east passes 4 or 5 miles south of the delta or plain (at 930 feet, barometer, above tide) east of Malone. The continuation of this line passes Covey Hill, where Woodworth and myself noticed the remains of an old water level at about 900 feet.

But the most important feature about Covey Hill is located on its eastern side, known as the "Gulf." This is a narrow, deep gorge, a few hundred yards in length, situated in an outer canyon over a mile long, with a pond at its head, at an elevation of 915 feet. This corresponds to the level of the Iroquois Beach farther west. The floor of this outer valley represents a baselevel of considerable duration, perhaps equal to that of the Iroquois Beach, with which it may be correlated until more complete surveys have been made. It is the strongest evidence of a long-continued water level near this elevation. It is about 100 feet below the depression across Covey Hill, which has been regarded as the spillway of a glacial lake, or approximately the difference between the higher terraces and the Iroquois level, occurring in the Mohawk Valley and also north of the Adirondacks. If this be the correct interpretation, as I believe, it is confirmatory of my suspicion, as expressed in my last year's paper,[8] that the spillway across Covey Hill belongs to a water level anterior to that of Lake Iroquois.

The extension of the Iroquois plane to the northeastern angle of the Adirondacks highlands indicates that the isobars have the direction of north 67° east, or that the rise of the land is in a direction of north 23° west. It has already been shown (from triangle 12) that the deformation crossing this isobar westward of Parishville reaches 6 feet per mile.

There is no reason to suppose that the rate of deformation at right angles to this isobar differs greatly in the vicinity of Covey Hill from that which obtains farther west. However, the rate of tilting to the southward naturally diminishes, as in the region of the Mohawk Valley; and indeed, in proceeding southward along Lake Champlain, Professor Woodworth found such to be the case, as shown in his excellent memoir.[9]

Deformation observed in the marine Beds at Montreal

Above the marine terraces at Montreal other beds containing *Saxicava rugosa, Macoma grœnlandica,* etcetera, occur at elevations of 536 and 560 feet above sealevel. Again, in the angle of the river east of Mooers Forks, marine deposits were found by Doctor Woodworth at 340 feet above sealevel. The deposits of both localities are familiar to me. Their distance apart is 38 miles in a direct line nearly north and south. While the marine beds may have been somewhat higher in one or both localities, such have so far not been found, so that we may measure the approximate deformation by their differences of elevation, which is between 5 and 6 feet per mile. This agrees with the tilting of 5 to 6 feet per mile seen farther west.

The warping of the lower 525-foot beach at Covey Hill is reported (by Fairchild[10]) to be 3 feet per mile south 20° east. This is on a shoreline more recent than the Iroquois, where the deformation is less. Projecting this, the lower beach should reach an altitude at Montreal of about 645 feet, which is nearly 100 feet above the marine deposits found there, with no corresponding shoreline. This further discredits any correlation of the beach at the foot of Covey Hill, with marine deposits at Montreal.[11]

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[8] Bull. Geol. Soc. America, vol. 23, 1912, pp. 471-476.

[9] New York State Museum Bulletin No. 84, chart P, opp. p. 226.

[10] Ib., Bull. 158, 1912, p. 33.

Present Stability of the Lake Region

The measurements now obtained show that the deformation of the region between the head of Lake Ontario and Parishville amounts to 540 feet, or 680 feet if it be measured from the head of Lake Erie. Between the outlet of Lake Huron and the highland, beyond the northeast angle of Georgian Bay, nearly an equal amount has been found. These changes have occurred since the birth of Niagara Falls, which I have computed at 39,000 years ago. A rise of somewhat more than 100 feet at the northeast angle of Georgian Bay, in excess of that at the outlet of Lake Huron, occurred since 3,500 years ago.[12] Let us see what is the status at the present day.

The intake of the Welland Canal (Port Colborne) is situated about 160 miles northeast of Cleveland, where at both places the daily fluctuations of Lake Erie have been recorded for over fifty years. The postglacial rise between these points has been 120 feet. As the bench-marks are permanent, any earth-movement should have become apparent in the water level. I have taken the mean levels of each day for periods of five years with the following results. For convenience in calculation the water at Port Colborne was assumed to be 0.33 foot below the Cleveland level.

The mean difference of level recorded gives the following figures:

Level at Port Colborne below that at Cleveland[13]

1855–1859	—.29 foot.
1860–1865	+.07 "
1866–1870	—.06 "
1871–1875	—.13 "
1876–1880	—.27 "
1881–1885	—.26 "
1886–1890	—.20 "
1891–1895	—.26 "
1896–1900	—.29 "
1901–1905	—.28 "
1906–1910	—.24 "
1911–1912	—.26 "

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[11] Bull. Geol. Soc. America, vol. 23, 1912.

[12] J. W. Spencer: Evolution of the Falls of Niagara, etc., Geological Survey of Canada, 1907, p. 376.

[13] Ib., chapter 31.

The probable errors in observation might reach a variation of 0.05 foot. It will be seen that there was no difference of level at the two localities for the quinquennial periods, one ending with 1859 and the other with 1900, or practically even with 1910. Variations may be seen in the early years. These would indicate a sinking at Port Colborne more than at Cleveland, and a rise again to the normal state if they could be attributed to earth-movements. From the full study it is apparent that there has been no change of level in 57 years, although there had been such great deformation at an earlier date. The present time is one of rest, as is also shown by Dr. D. W. Johnson's present fixity of the border of the continent, in contrast with the recent great elevation during the time of making the submarine canyons, such as those of the extended Hudson River and Gulf of Saint Lawrence.

These results disprove my original suggestion (1894) that the Niagara discharge would be turned into the Mississippi in the not distant future. This idea was expanded into a monograph[14] on earth-movements by Dr. G. K. Gilbert, who used the fluctuations of the lakes; but in so doing he took the levels of a few isolated days, irregularly selected. The erroneous results derived therefrom have been widely quoted, but the table given above contains the proof of the present stability of the lake region.[15]

RESULTS

By triangulating the Iroquois, Algonquin, and other beaches, the dome of the greatest deformation of the Great Lake region is found to be situated approximately in latitude 49° north, longitude 76° west, whence it extends to latitude 50° 30′ north, longitude 75° west. This is confirmed by the course of the drainage of the highlands. It is the locality where the "height of land" reaches its most southern lobe.

Although the Adirondacks form an outlier of the Laurentian Mountains, yet they have produced very little effect on the deformation of the earth's crust, as shown by the raised beaches. This is seen on proceeding eastward from the head of Lake Erie, where the old shorelines are still almost horizontal. At the head of Lake Ontario the rise is 2 feet per mile north 22° east; but on approaching the 76th meridian the eastern equivalent in the warping entirely disappears, while that in the northward direction increases from 3 feet per mile in the Mohawk Valley to 6 feet per mile on nearing the Saint Lawrence River.

On passing the 76th meridian the direction of the uplift becomes north-northwest and the zones of equal rise become somewhat parallel to the direction of the Saint Lawrence River, as might be expected from the change of course of the "height of land" (as shown on the map), to which the isobars are parallel farther southwestward.

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[14] Eighteenth Ann. Rept. U. S. Geological Survey, part II, 1898, pp. 601-647.

[15] Falls of Niagara, chapter 31.

Beyond the locality where the beaches can be triangulated, the same amount of deformation is observed in the marine beds at Montreal and those on the northeast flanks of the Adirondacks mass. These diminish in height on proceeding farther south, as shown by Woodworth, who finds that they do not extend beyond the head of the Champlain Valley.

The measured earth-movements, aggregating 540 feet between the head of Lake Ontario and Parishville, have occurred since the birth of Niagara Falls—39,000 years ago. Part of the deformation has taken place within 3,500 years, but for a period of over a half a century we have definite physical proof that there have been no earth-movements in the lake regions.

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RELATIONSHIP OF THE GREAT LAKE BASINS TO THE NIAGARA LIMESTONE[1]

BY J. W. SPENCER

(Presented before the Society in abstract December 31, 1912)

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NIAGARA LIMESTONE BARRIERS TO THE LAKES

The dependence of diverse topographic forms on geological structure is nowhere better illustrated than in our Great Lakes. The valleys are excavated in shales, soft and impure limestones and sandstones, with their development retarded by the occurrence of overlying beds of hard rock. Such strata, consisting of the Niagara limestone, have given rise to the separation of the basins of five of the Great Lakes, that of Georgian Bay being distinct from the basin of Lake Huron. This feature is true, although the lakes trend in every direction, as is shown on the accompanying map.

Underlying the superficial drift the Niagara limestone forms the rock-floor of the country for a breadth of 5 or 6 miles or perhaps even 20 miles. This formation constitutes a barrier to Lake Erie, separates Georgian Bay from Lake Huron, and Green Bay from Lake Michigan, and finally forms a wall between the southeastern part of Lake Superior and lakes Michigan and Huron.

In the evolution of the valleys of the lakes the less durable strata were removed from a broad extent of country, but the drainage from each of these was forced to cross the hard barriers, which thus gave rise to their relatively narrow outlet. At the same time this zone of durable limestone became a more and more prominent tableland as the valleys were being more easily deepened. But the rains and the small streams grad-

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[1] Manuscript received by the Secretary of the Society March 3, 1913.

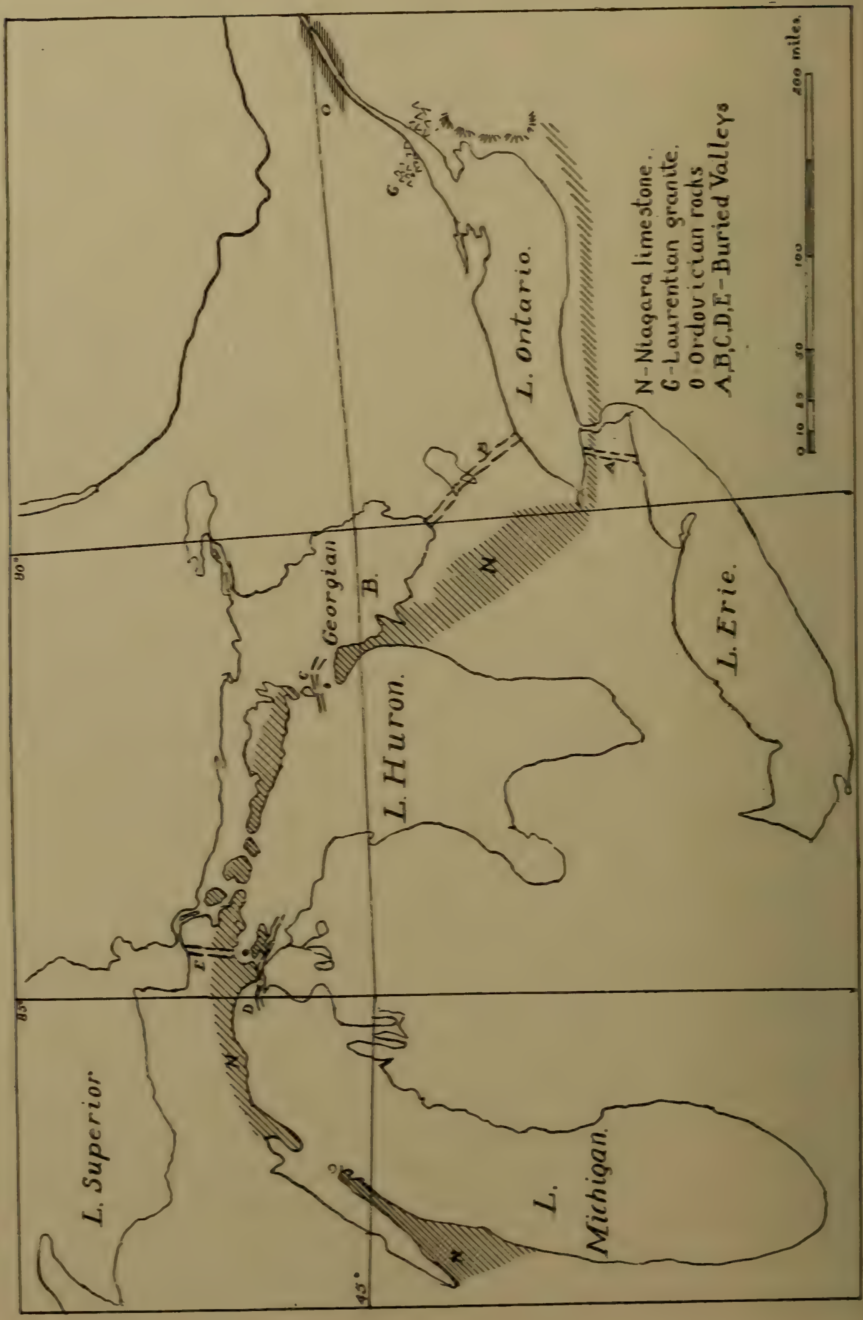
L. Superior
L. Michigan.
L. Huron.
Georgian
B.
L. Ontario.
L. Erie.
N
N
N
G
O
O
A
B
C
D
E
80°
85°
45°
N-Niagara limestone.
G-Laurentian granite.
O Ordovician rocks
A,B,C,D,E-Buried Valleys
0 10 25 50 100 200 miles.

FIGURE 1.—Map showing Effects of the Niagara Limestone in the Evolution of the Lake Basins

ually dissected the plateau into separated masses, such as those which on subsequent submersion now form the island chain north of Lake Huron. Similar preglacial features occur elsewhere now buried beneath the mantle of drift.

CONCERNING THE PREGLACIAL ERIE OUTLET

At least three depressions below the Erie level cross the Niagara limestone belt between it and Lake Ontario. These have been found by borings. The deepest of them is the Erigan Channel, situated 12 to 14 miles west of Niagara Falls (A on map). This was the great preglacial outlet of the upper valley. At its northern end may be observed one of the deep indentations in the face of the Niagara escarpment; otherwise the ancient valley is entirely concealed by drift for the remainder of the distance across the peninsula between the two lakes, but borings have been made for almost every mile of the way. I regard the discovery of this channel with considerable pride, as exceptionally complete results have been obtained. These have been described in my book on Niagara.[2] However, since its publication additional borings have been made showing its depth; which within the line of the escarpment reaches to a depth at least 375 feet below the Erie level or 50 feet beneath the surface of Lake Ontario. This one newly observed feature is worthy of record. Thus this buried channel is sufficiently deep to have drained the Erie basin without adding to it the effects of the recent earth-movements. These would reduce the floor of the channel to 500 feet below the present lake level at Cleveland. Its breadth of a mile and a quarter to 2 miles is small compared with that of the lake, but this is due to the protecting effects of the harder capping rocks, while the channel itself was largely made by the river flowing through it.

HURON AND GEORGIA OUTLETS

The connection between the Huron and Erie basins is entirely modern, the preglacial outlet of the upper valley having passed by way of Georgian Bay to that of Lake Ontario (B on map), through a broad buried valley, which I discovered in 1888.[3] This was excavated out of Hudson River and Trenton formations; but the Huron drainage had also broken across the Niagara belt (C on map). The outlet of the Huron Valley is now submerged between the Sangeen Peninsula and the islands, having a breadth of 4 miles for the outer and 2 miles for the inner channel. It is cut through the hard rocks into the softer strata, but here the channel is more or less obstructed by drift.

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[2] Evolution of the Falls of Niagara, chapter 37, Geological Survey of Canada, 1907.

[3] Proc. American Assoc. Adv. Sci., vol. 37, 1888, pp. 197-199.

CONCERNING THE OUTLET OF LAKE MICHIGAN

The features of the outlet of this lake are similar to those of Lake Huron, just mentioned, except that some higher Silurian strata overlie the Niagara limestones, all of which have been penetrated by the channel, which has also been partly filled with drift (D on map). The depth of the buried valley is further indicated by borings just to the south (at Cheboygan), which reach to more than a hundred feet below the drift-covered floor of the straits. The submerged canyon of Grand Traverse Bay, to the southwest, shows still better the depth of the preglacial channels, to over 600 feet below lake level. Green Bay came very nearly being a separate lake, due to the same geological formations.

OUTLET OF LAKE SUPERIOR

The same belts of hard rocks separate Lake Superior from lakes Michigan and Huron. These are penetrated by a channel, some two miles wide, between Lake Superior and Lake Huron, as shown at E on the map (Leverett). Thus it is found that even this lake owes part of its configuration to the Niagara formation.

ONTARIO-SAINT LAWRENCE VALLEY

The Saint Lawrence Valley is only a continuation of that of Lake Ontario, where the southern highlands bounding the ancient broadened channel still remains, although largely composed of shaly and soft strata. Along one section of the waterway these strata were removed, exposing for a few miles the underlying crystalline rocks. Among them, deep channels had early been produced. These drift-filled and do not entirely form the barrier to the lake, which is otherwise composed of the Calciferous formation, beginning only 66 miles below its outlet. Even here other buried channels occur, so that the rocks which give rise to the rapids of the Saint Lawrence are only spurs between the ancient courses of the streams, now largely concealed beneath drift.

RESULTS

Thus it is shown that Superior, Michigan, Huron, and Erie, with their diverse configuration, owe the existence of their separate basins largely to the distribution of the Niagara limestone underlaid by softer strata. Georgia and Ontario are due to the softer Silurian and older rock formations without the presence of the hardest layers, so that their outlets are characterized by broader valleys which are also of greater antiquity. These observations relate to the valleys of the lakes and not simply to their basins, which result from the obstruction of the ancient outlets by the accumulation of drift and by the postglacial deformation due to earth-movements.

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SPIRIFEROIDS OF THE LAKE MINNEWANKA SECTION, ALBERTA[1]

BY H. W. SHIMER

(*Read before the Paleontological Society December 31, 1912*)

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INTRODUCTION

Lake Minnewanka, or Devils Lake, is situated about 9 miles northeast of Banff, in the Rocky Mountains of western Alberta. The section was made along the northwest shore of the lake and continued westward across the Cascade River.

The following formations are included:

PERMIAN

	Feet
Upper Banff shale; an alternation of heavy bedded, light gray calcareous sandstones and thin-bedded, dark gray arenaceous shales. Many Lingulæ and pelecypods (as Schizodus)	1,200

PENNSYLVANIAN

Rocky Mountain quartzite; an alternation of light gray quartzite and light gray limestone. *Euphemus carbonarius* is very abundant in the upper portion	600
Upper Banff limestone; light to dark gray limestone, usually thin-bedded. The lower portion is of Mississippian age	2,200

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[1] Published by permission of the Director of the Canadian Geological Survey.

Manuscript received by the Secretary of the Paleontological Society January 28, 1913.

	Feet
MISSISSIPPIAN	
Lower Banff shale; dark gray to black calcareous shale	1,300
DEVONIAN	
Lower Banff limestone; heavy bedded, light gray limestone	1,000
Intermediate limestone; alternating fine to coarse grained limestone	1,600

The spiriferoids are distributed as follows:

Pennsylvanian (Upper Banff limestone, upper portion):

Spirifer rockymontanus.
Spirifer cameratus.

Mississippian (Upper Banff limestone, lower portion, and Lower Banff shale):

Spirifer centronatus.
Spirifer centronatus albapinensis.
Spirifer striatus.
Spirifer striatus madisonensis.
Ambocœlia umbonata.
Reticularia pseudolineata.

Devonian (transition beds from Lower Banff shale to Lower Banff limestone, and Lower Banff limestone):

Spirifer notabilis.
Spirifer whitneyi animasensis.
Cyrtia cyrtiniformis.

AFFINITIES OF THE FAUNA

28, 1912.

Perhaps the most interesting feature of the fauna next to its abundance is its close affinity with those of the Yellowstone Park and of Colorado. The spirifers of localities 20 to 35 present a distinctly Madison aspect, as that aspect is described by Girty in his "Monograph on the Yellowstone National Park." The especially noteworthy feature common to the two localities is the dominating abundance of *Spirifer centronatus* represented by both the typical species and the variety *albapinensis*.

Similar relationship is seen to exist between the spirifers of the beds transitional from the Lower Banff limestone to Lower Banff shale (locality 38) of the Canadian region and the Devonian fauna of the Ouray limestone of Colorado, described by Kindle (Bulletin of the United

States Geological Survey, number 391). Two forms first described by Kindle from Colorado, *Spirifer notabilis* and *S. whitneyi animasensis*, are among the common spirifers of the Canadian section.

The Hamilton and Chemung species are the more cosmopolitan species of the Devonian of New York and the Mississippi Valley.

Since *Spirifer rockymontanus* and *S. cameratus* are widely distributed species, their presence in the Lake Minnewanka region indicates merely a broad general relationship with the Pennsylvanian of the Mississippi Valley and the Rocky Mountains.

Description of Species

DEVONIAN

Spirifer notabilis Kindle

The Canadian specimens show distinctly the characteristic slender mucronate extensions, and especially the most striking peculiarity of this species as described by Kindle,[2] namely, the nature and direction of the plications on the wings. The first six plications on each side of the sinus originate at the beak and diverge anteriorly, as usual in Spirifer. The remainder of the plications, however, lying between these and the extremities of the hinge originate at the hinge line instead of at the beak, thus constituting a second series of plications with a different direction from the former. Where the two series meet there is a marked divergence, the outer series bending abruptly away from the inner. Lamellose concentric growth lines cross the radiating plications.

Range.—*Spirifer notabilis* has been found in Colorado and New Mexico. In the Lake Minnewanka section it characterizes the transition beds between the Lower Banff shale and Lower Banff limestone.

Spirifer whitneyi animasensis (Girty)

This variety is distinguished from the species by the highly elevated area of the pedicle valve and its slightly twisted and but slightly incurved beak. The plications are very fine and of about equal size over the whole shell.

Range.—Described by Girty from Colorado and by Kindle[3] from New

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[2] E. M. Kindle: The Devonian fauna of the Ouray limestone. U. S. Geological Survey Bull. 391, p. 26, pl. 7, fig. 3-6*c*.

[3] E. M. Kindle: The Devonian fauna of the Ouray limestone. U. S. Geological Survey Bull. 391, p. 25, pl. 9, figs. 1-3*a*.

Mexico. At Lake Minnewanka it is common in the transition beds between the Lower Banff shale and the Lower Banff limestone.

Cyrtia cyrtiniformis Hall and Whitfield

This species is represented by numerous and quite well preserved specimens. Their average size is much larger than the type from the Chemung at Rockford, Iowa. The latter, an averaged sized specimen, has a width of 11 millimeters; height of cardinal area of pedicle valve, 9 millimeters; length of brachial valve, 12 millimeters, as against 21, 12, and 19 millimeters (23 millimeters along the curvature) for a medium sized specimen from the Lake Minnewanka section. The pedicle valve of the latter has a slightly more incurved cardinal area. The proportions of the delthyrium are similar, as well as the number of plications, on each side of the fold and sinus—that is, about 20—for here the plications are simple; but as those on fold and sinus bifurcate the number here has increased on this enlarged shell to 20 at the anterior edge, resulting in about 60 plications to a valve as against 45 to 50 in the Iowan forms.

The mature shell is slightly incurved at the front, owing to a greater development of the median sinus, though even in the young shell this is more highly developed than in the Iowan forms. The young shell likewise is considerably wider than long.

In size it is similar to the form noted by Whiteaves from the Hay River, Mackenzie, but this has only 29 or 30 plications to each valve.

Range.—Chemung of Iowa and Hay River. At Lake Minnewanka it is very common in the transition beds from the Lower Banff shale to the Lower Banff limestone, and likewise common in the uppermost portion of the latter.

MISSISSIPPIAN

Spirifer centronatus Winchell

This is the most abundant spiriferoid of the Lake Minnewanka area. It ranges through the entire Mississippian series of beds, a thickness of 2,000 feet, and is represented in local areas throughout this series by immense numbers of individuals.

In its range from bottom to top of these strata, the species undergoes certain variations, while in the lower portion of the Lower Banff shale it is represented by the variety *albapinensis*. It was during the deposition of the upper portion of the Lower Banff shale that the species attained its most typical form.

S. centronatus var. *albapinensis* Hall and Whitfield

This form was described by Hall and Whitfield[4] as a species distinct from *S. centronatus,* and distinguished from it especially by the character of the median sinus. In *albapinensis* the median sinus is sometimes smooth, sometimes marked by two or three plications, which are always faint and do not extend beyond the anterior half of the shell. The sinus is bordered on each side by a broad, rounded plication, which does not bifurcate as in *S. centronatus,* but continues prominent to the anterior margin of the shell and undivided, except at times by a slightly impressed line on the lower half.

These are considered only varietal differences by Girty[5] and as representative of the condition of most young shells.

The Lake Minnewanka specimens of this variety are of very differing sizes, even from the same bed. Thus in locality 35 (lower portion of the Lower Banff shale), which is especially characterized by this type of Spirifer, an exceptionally small specimen is 6 millimeters long by 9 millimeters broad, with about 12 plications on each side of the sinus, while a specimen somewhat larger than the average measures 15 by 28 millimeters, with about 18 plications on each side of the sinus. All the forms agree, however, (*a*) in the great breadth and prominence of the plications bounding the sinus and in their undivided character, except for a slight flattening which at times develops into a faint mesial depression; (*b*) in the absence of plications in the sinus and in its peculiarly broad, low flattened appearance; (*c*) in the appearance of the median fold, which is quite prominently elevated and expands rapidly from the beak to the front of the shell. It is impressed by a median line, and each of its two halves thus formed is again in many cases divided by a shallow sinus which extends up only a short distance from the anterior margin.

The typical *S. centronatus* appears first in great abundance in the upper portion of the Lower Banff shale. As there represented, it agrees exactly with Girty's description and figures of the species as found in the Yellowstone Park and in Nevada and Utah.[6]

The undivided bounding plications of the sinus of *albapinensis* have here bifurcated near the beak, so that they lose their prominence and approach the lateral plications in size. The sinus is characterized by six or more plications and the fold is from the beginning divided into two plications, which subsequently bifurcate; the fold thus toward the anterior margin bears usually four plications, sometimes six, and all of nearly equal size.

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[4] Geology of the 40th parallel, vol. 4, p. 255.

[5] Geology of the Yellowstone National Park. U. S. Geological Survey Monograph 32, p. 548.

[6] Geology of the Yellowstone National Park. U. S. Geological Survey Monograph 32, part 2, p. 547.

As in the Canadian region, so in the Yellowstone Park, *S. centronatus* is by far the most abundant and universal form.

Range.—It has been observed in a wide geographical range, having been described from the Waverly of Ohio, Iowa (Kinderhook), Black Hills, Wyoming, Montana, Wasatch Range of Utah, and Nevada.

Spirifer striatus (Martin)

Our specimens agree with this species in their regularly arched cardinal area of pedicle valve, the character of sinus and fold, and in the number of plications (on sides of shell about 10 in one-half inch one inch from beak). They vary in length of hinge line from 35 to 70 millimeters, but the European specimens of this species vary likewise greatly in size.

Ours agree with Hall and Whitfield's Utah specimens apparently in all respects except in the low cardinal area of their forms; but since theirs were crushed this may be due to that fact.

Horizon.—Mountain limestone of Europe, Mississippian of Utah, Nevada, New Mexico; also reported from the Pennsylvanian of Utah and New Mexico. At Lake Minnewanka it is common in the upper portion of the Lower Banff shale.

Spirifer striatus madisonensis Girty

A single brachial valve agrees with this variety in its size, its coarse plications, and the character of the median fold.

Horizon.—Madison limestone of Yellowstone National Park; lowest portion of Upper Banff limestone, Lake Minnewanka.

Ambocœlia umbonata (Conrad)

Our specimens agree in every respect with the descriptions and figures given by Hall.[7]

Range.—Upper Devonian of New York and Pennsylvania, Waverly (Bedford shale) of Ohio. At Lake Minnewanka it is common in the lower portion of the Lower Banff shale.

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[7] Paleontology of New York, vol. 4, pp. 259, 260, pl. 44.

Reticularia pseudolineata (Hall)

These specimens are very similar to those from the type locality at Keokuk, Iowa. One pedicle valve measured 36 millimeters wide and 26 millimeters long. The spinose ridges are pronounced. The median sinus of the pedicle valve is somewhat more pronounced than the median fold of the opposite valve, but both are broad and but slightly developed, disappearing toward the beak.

Range.—Burlington to Keokuk of Indiana, Illinois, Iowa, Missouri. At Lake Minnewanka it is common in the upper portion of the Lower Banff shale.

PENNSYLVANIAN

Spirifer rockymontanus Marcou

The Lake Minnewanka specimens are in close agreement with those described and figured by White from Utah and New Mexico.[8]

The usual transverse diameter of the Canadian specimens is about 30 millimeters. There are about 10 well marked simple plications on each side of the fold and sinus; there are four on the fold, sprung by dichotomizing from the original single plication at the beak. The hinge extremities are rounded and the hinge in most instances is slightly shorter than the width of the shell below. There seems to be a close affinity between *S. rockymontanus* and *S. centronatus*. While typical examples of the species are easily distinguished from each other, certain other examples are not so easily distinguishable. *S. rockymontanus* is usually larger, with rounded hinge extremities, and its ornamentation has a much coarser aspect, owing to the coarser and sharper plications and their smaller number both on fold and sinus and on the lateral slopes. There is likewise apparently no tendency toward the breadth and prominence of the bounding plications of the sinus seen so characteristically in *S. albapinensis* and persisting to an occasionally obvious degree in *S. centronatus.*

Range.—Widely distributed in the Pennsylvanian from Ohio and West Virginia to New Mexico, Utah, and Colorado. At Lake Minnewanka the most common Spirifer of the upper portion of the Upper Banff limestone, though never occurring in very great abundance.

Spirifer cameratus Morton

The specimens from Lake Minnewanka are poorly preserved, but the characteristic fasciculation of the plications is well seen in some of the forms.

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[8] Geology of the 100th meridian, vol. 4, p. 134, pl. 11, figs. 9*a*, *b*, *c*, *d*.

Range.—Extensively distributed in both the Mississippi Valley and the Rocky Mountains. At Lake Minnewanka it is common—the most abundant if not the only Spirifer—in the upper portion of the Upper Banff limestone.

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HOMOLOGY OF THE "LACRIMAL" AND OF THE "ALISPHENOID" IN RECENT AND FOSSIL REPTILES[1]

BY WILLIAM K. GREGORY

(*Presented before the Paleontological Society December 30, 1912*)

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PREFRONTAL, LACRIMAL, ADLACRIMAL

In the skull of lizards there is a large triangular bone lying in the anterior part of the orbit, above and behind the maxillary and below the frontal. This bone, or pair of bones on opposite sides, is commonly called the prefrontal. This prefrontal of lizards has been shown by Gaupp[2] to resemble the lacrimal of mammals—that is, it has similar relations to the surrounding bones, to the lacrimal duct, and to the underlying cartilage skull in the embryo. On account of these resemblances between reptilian prefrontal and mammalian lacrimal, Gaupp believes that these elements are homologous with each other, and hence he has given up the name prefrontal for the reptilian element and calls it instead lacrimal, in order to make the terminology of the reptilian skull conform with that of the mammal.

What, then, is that other bone of the lizard skull which until Gaupp's time has generally been called lacrimal? This is a small or vestigial element lying below the large triangular bone and above the alveolar border of the maxillar. Gaupp thinks that this vestigial element has no right to the name lacrimal, no matter how long it has borne that name, and hence he calls it adlacrimal, while Jackel calls it postnasal.

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[1] Manuscript received by the Secretary of the Paleontological Society January 11, 1913.

[2] Das Lacrimale des Menschen und der Säuger und seine morphologische Bedeutung. Anat. Anz. Bd. 36, 1910, pp. 529-555.

In his paper of 1910, in which these views are expressed, Gaupp bases his conclusions entirely on the morphology of recent reptiles, especially the lizards. The lizards on account of their streptostylic quadrate are believed by him to represent ancestral mammalian conditions in many parts of the skull.

What is the paleontological evidence in these questions of homology?

In the Permian Cotylosaurs the lacrimal (Gaupp's adlacrimal) instead of being vestigial, as in lizards, is a large bone that shows no signs of being crowded out by the prefrontal. In *Labidosaurus,* for example, Professor Williston[3] describes the lacrimals as lying in the anterior border of the orbits (of which border they form the greater part), thence extending forward, parallel to the maxillaries, to the anterior nares. The lacrimals are equally large[4] in *Seymouria, Limnoscelis, Captorhinus, Varanosaurus,* and other genera.

In the lowest members of the mammal-like series, namely, the Therocephalia,[5] the lacrimal has been crowded away from the anterior nares by the upgrowth of the maxillary, so that it has lost its anterior extension and has begun to look like a mammalian lacrimal. In the higher Therapsida or Cynodontia[6] the lacrimal is a prominent bone on the anterior border of the orbit, which articulates with the jugal, maxillary, nasal, and prefrontal. In *Diademodon,* according to Watson,[7] the lacrimal is pierced by a lacrimal foramen and forms a part of the floor of the orbit.

Hence Gaupp's views regarding the lacrimal receive no support whatever from the Cynodonts. On the contrary, if the Cynodonts are nearer to the mammals than the lizards are, as there is good reason to believe, then we must assume that in lizards and *Sphenodon* the prefrontal has merely usurped the place of the true lacrimal, which has been crowded out and become vestigial.

ALISPHENOID AND ORBITOSPHENOID

Gaupp has also raised an important question as to the homology of the reptilian alisphenoid, denying that it is homologous with the true alisphenoid of mammals.[8]

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[3] The skull of Labidosaurus. Amer. Jour. Anat., vol. 10, 1910, p. 73.

[4] See the figures in Williston's American Permian Vertebrates. Univ. Chicago Press, 1911.

[5] See Broom: A comparison of the Permian reptiles of North America with those of South Africa. Bull. Amer. Mus. Nat. Hist., vol. 28, 1910, pp. 204-213.

[6] See Broom: On the structure of the skull in the Cynodont reptiles. Proc. Zool. Soc., 1911, pp. 896-915.

[7] The skull of Diademodon, with notes on those of some other Cynodonts. Ann. and Mag. Nat. Hist., (8), vol. viii, 1911, p. 311.

[8] Über die Ala temporalis des Säugeschädels und die Regio Orbitalis einiger anderer Wirbeltierschädel. Merkel und Bonnets Anat. Heft lxi (19 Bd., Heft 1), 1902, pp. 221-222.

The alisphenoids of mammals in the developing cartilage skull are represented by a pair of winglike outgrowths, called the alæ temporalis, which project widely from either side of the basisphenoid. These temporal wings lie below the roots of the trigeminus nerve and both in front and outside of the carotid foramina. Accepting ontogeny as in some measure an indication of phylogeny, Gaupp concludes that the mammalian alisphenoids arose outside of the primary brain-case and have only secondarily grown up around the outer side of the fifth nerve, and thus have come to shut in the open space between the auditory capsule and the cartilage orbitosphenoid. In the chondrocranium of the lizard the basipterygoid processes of the basisphenoid, like the alæ temporalis of mammals, project widely from either side of the cartilaginous basisphenoid; they also lie below the roots of the trigeminus and in front of the foramina for the carotids. Hence Gaupp homologizes these basipterygoid processes in the lizard with the cartilaginous alisphenoid wings of mammals. These basipterygoid processes he supposes to have become turned upward, so that they covered the roots of the trigeminus externally; by further upgrowth of the replacing bone they covered the temporal region of the skull.

If the reptilian basipterygoid processes alone represent the cartilaginous alisphenoids of mammals, as Gaupp maintains, then it follows that that pair of bones in the temporal region of reptiles which have been called alisphenoids must represent some other elements. Doctor Von Huene[9] accepts Gaupp's views and applies them in the field of paleontology. He says (1911) that the name alisphenoid should no longer be applied to Sauropsidan skulls; that the bone formerly called alisphenoid in the Sauropsida is identical with the orbitosphenoid of mammals. Consequently in all his recent papers on fossil reptiles the bones usually called alisphenoids are lettered orbitosphenoids, the lacrimals are called adlacrimals, and the prefrontals are called lacrimals.

Gaupp's conclusions regarding the alisphenoid were based very largely on a comparison of lizard and mammal in embryonic stages without reference to paleontological evidence. In order to test Gaupp's conclusions, I have studied the composition and elements of the brain-case in many recent and fossil reptiles, especially Cotylosaurs, Cynodonts, Dinosaurs, Crocodiles, *Sphenodon*, etcetera, primarily from specimens, but also as they are described in recent papers by Williston, Broom, von Huene, Watson, and others. I have come to directly opposite conclusions to those of von Huene and Gaupp, although at first inclined to accept them.

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[9] Beiträge zur Kenntniss und Beurteilung der Parasuchier. Koken's Geol. u. Pal. Abhandl., n. F. Bd. 10, 1911, p. 43.

The evidence is too detailed to be presented adequately at this time and will shortly be published in the American Journal of Morphology, but in outline it is as follows: Some of the distinguishing features of the mammalian alisphenoids are: that they are lateral to the basisphenoid and pituitary fossa; they lie between the orbitosphenoids and the otic capsule; they connect above with the parietals; they are largely in front of the foramen for the mandibular branch of the fifth nerve and behind the fissure which gives exit to nerves III, IV, V^1, and VI. Further, the temporal wings of the alisphenoid lie outside the roots of the fifth nerve; they also are external to the carotid foramina and postero-external to the pterygoid processes. In Cynodonts there are a pair of elements in the temporal region of the skull which are described and figured by both Broom and Watson and which are homologized by them with the temporal wings of the mammalian alisphenoids. These alisphenoids of Cynodonts correspond with the mammalian alisphenoids in all the more important topographic relations, so that their homology can hardly be doubted.

The alisphenoids of Cynodonts in turn appear to afford a perfect transition to those of typical reptiles. In all their relations to surrounding bones and to foramina their essential agreement with the alisphenoids of *Tyrannosaurus,* for example, can hardly be denied. For these reasons I feel pretty confident that the elements commonly called alisphenoids in Crocodiles and Dinosaurs are rightly so named, and that von Huene is wrong in calling them orbitosphenoids. The true orbitosphenoids were, I think, correctly named by Parker in the Crocodile. They lie immediately behind the ethmoid, below the frontals, and in front of the alisphenoids. In *Tyrannosaurus* they are continuous below with the presphenoid and are, I think, incorrectly named presphenoid by Doctor von Huene.

Pterygoid, Epipterygoid, and Alisphenoid

Another side of this thorny subject is the question of the relations of the pterygoid, epipterygoid, and alisphenoid. Broom[10] has ably defended the view first expressed by Parker that the temporal wings of the alisphenoids have been derived from epipterygoids, like those of *Sphenodon,* and that the alisphenoid represents a portion of the primitive pterygoquadrate cartilage. In *Sphenodon* the alisphenoids, or epipterygoids, lie immediately in front of the proötic foramen and below the parietals. They differ from the alisphenoids of Dinosaurs chiefly in retaining their primitive connection with the pterygoids, a connection which has been lost in the Dinosaurs and Crocodiles. In *Diadectes* the alisphenoids, or epipterygoids, have essentially the same relations as in *Sphenodon.* Watson[11] goes even further than Broom; he finds that in Cynodonts there is no suture separating the temporal portion of the alisphenoid from the pterygoid. He shows that the basal portions of the pterygoids in all their relations with surrounding bones and nerve openings correspond precisely with the basal portion of the alisphenoids, and that the temporal portion of the pterygoids correspond with the temporal portion of the alisphenoids.

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[10] Observations on the development of the marsupial skull. Proc. Linn. Soc. New South Wales, vol. 34, pp. 211-212.

Watson also holds that the true mammalian pterygoids have not been derived from the reptilian pterygoids at all, but from the ectopterygoids, or transverse bones, as originally suggested by Seeley. Watson's thorough analysis of the topographic relations of the elements in question virtually amounts to a demonstration of the suggested homologies, provided one accepts on other grounds the view that the Cynodonts are closely related to the stem of the Mammalia. The view that the basal portion of the reptilian pterygoid gave rise to the basal portion of the alisphenoid also explains in a very satisfactory manner the fate of the reptilian pterygoid. The backward extension of the palatines, carrying with them the ectopterygoids and separating them from their primitive connection with the maxillaries, also offers a highly reasonable explanation of the peculiar position of the mammalian pterygoids and does away with the necessity for regarding the so-called pterygoid wings of the alisphenoids as neomorphs in mammals. But what of Gaupp's view that the mammalian alisphenoids have been derived from basipterygoid processes, such as are seen in lizards?

In the Cynodonts, as described by Broom and Watson in the place of the basipterygoid processes, we observe flanges of the alisphenoid which firmly embrace the basisphenoid on either side. These flanges are external to the openings identified by Broom as the carotid foramina; they are external and inferior to the roots of the trigeminus nerve. In these relations they parallel the basipterygoid processes of the lizard and are homologous with the alæ temporalis or cartilage Anlage of the alisphenoids of mammals.

Hence I think that Gaupp's comparisons of embryo lizards and embryo mammals do not prove that the mammalian alisphenoids are homologous with the lizard basipterygoid processes, but that the resemblances observed are due to the mammalian alisphenoids having retained certain relations which were already established in the Cynodonts.[12]

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[11] The skull of Diademodon. . . . Ann. and Mag. Nat. Hist. (8), vol. viii, 1911. p. 305.

Mutability of Names in reptilian Osteology

The questions thus briefly touched on have, I think, more than an academic interest to paleontologists. They raise the question whether paleontologists will permit the nomenclature of the reptilian skeleton to be indefinitely upset and confused. The naming of elements in lower vertebrates in accordance with their supposed homologies in mammals has indeed been the historic process, but it is having the same disturbing effect on anatomical nomenclature as the search for prior names has had on systematic nomenclature. Gaupp, as we have seen, shifts the name lacrimal from one bone to another, and von Huene performs the same kind office for the orbito-, ali-, and presphenoids.

Supposing Watson is right in holding that the mammalian alisphenoid has been derived from the reptilian pterygoid, plus epipterygoid, and that the mammalian pterygoids in turn have been derived from the ectopterygoids; shall we therefore transfer the name pterygoid from the pterygoid to the ectopterygoid, and shall we call the pterygoid alisphenoid? Would it not be more sensible to say that the reptilian pterygoid was still the pterygoid; that the ectopterygoid was still the ectopterygoid, no matter what they subsequently gave rise to in the mammals?

Similarly, would it not be well for those who believe that the reptilian quadrate was transformed into the mammalian incus to continue to apply these names in the respective classes?

Conclusions

(1) The prefontal of reptiles is not homologous with the lacrimal of mammals.

(2) The lacrimal of reptiles is homologous with the lacrimal of mammals.

(3) The alisphenoids of dinosaurs, etcetera, are not homologous with the orbitosphenoids of mammals, but in part with the alisphenoids of mammals.

(4) The pterygoids (including the epipterygoids) of reptiles probably gave rise to the alisphenoids of mammals (Watson).

(5) Transference of names from one element to another is highly objectionable. There is no practical necessity for invariably applying the same name to homologous elements in different classes.

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[12] This subject is more fully discussed in my forthcoming paper in the American Journal of Morphology.

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RELATIONSHIP OF THE TUPAIIDÆ AND OF EOCENE LEMURS, ESPECIALLY NOTHARCTUS[1]

BY WILLIAM K. GREGORY

(*Presented before the Paleontological Society December 30, 1912*)

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INTRODUCTION

When my friend Mr. C. W. Beebe was in Borneo he made persistent efforts to secure for me specimens of the rare pen-tailed tree-shrew (*Ptilocercus lowii*). Failing in this, he obtained the loan of a skin and skeleton of this animal from the Rajah of Sarawak, and these he has very kindly intrusted to me for study and description.

Ptilocercus and its ally, *Tupaia*, together constituting the family Tupaiidæ of the suborder Menotyphla, are of peculiar interest, because they appear to bridge over to some extent the gap that separates Insectivores from Primates. They are arboreal in habit, and *Tupaia* is said to be lively, active, and squirrel-like, both in appearance and in habit.

Certain anatomical resemblances shown by *Tupaia* to the Lemurs have been noted from time to time by various authors, but until recently the Tupaiids have been studied far less thoroughly than other families of Insectivores. In 1910 I published an analysis of the osteology of *Tupaia* and of other Menotyphla and summarized the evidence for the relationship of the Tupaiidæ with the Primates.[2] In the same year Dr. Walter Kaudern,[3] of Stockholm, observed many resemblances between *Tupaia* and the Lemuridæ in the structure of the male reproductive organs and in the abdominal musculature. Quite recently Dr. Elliot Smith,[4] accepting the theory that the Tupaiidæ show us what the ancestors of the Primates were like, says that they also illustrate the influence of an arboreal mode of life in stimulating, first, a great development of the centers of sight, sound, touch, and muscular sensibility; and, secondly, an arrest in the development of the olfactory centers, which are predominant in terrestrial Insectivores.

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[1] Manuscript received by the Secretary of the Paleontological Society January 11, 1913.

[2] The orders of Mammals, Bull. A. M. N. H., vol. 27, pp. 268-285, 321-322.

[3] Ueber einige Aehnlichkeiten zwischen Tupaja und den Halbaffen. Anat. Anz., 37. Bd. No. 21, 22, pp. 561-573.

TUPAIID OSTEOLOGY AND RELATIONSHIPS

The opportunity of studying the skeleton of *Ptilocercus* has led me to review the general subject of Tupaiid relationships. This phylogenetic problem may be stated as follows: Are the special resemblances between Tupaiids and Lemurs due largely to convergent evolution between widely removed phyla? Or are they due partly to homoplastic evolution in related phyla, which have been derived from a single family of Mesozoic Insectivores?

Some of the more important characters tending to ally Tupaiids and Primates are as follows:[5] The brain and brain-case of Tupaiids are far larger than in typical Insectivores; the eyes and orbits are large; the olfactory portions of the skull more or less reduced (especially in *Ptilocercus*); the orbits are inclosed posteriorly by a postorbital bar; the prominent malar is pierced by a foramen below the orbits, as in Lemurs; the malleus, incus, and stapes, according to Doran, in several features much resemble the Lemur and ceboid types; the large auditory bullæ are formed from the inflation of the entotympanic, the true or ectotympanic remaining as a bony ring, as in non-Malagasy lemuroids (van Kampen). The same authority notes the agreement in the course of the entocarotid artery with that of Lemuridæ, and further agreements are seen in the arrangement of the pterygoid region. *Tupaia* is stated to have a lemur-like sublingua; the abdominal musculature and male reproductive organs, as already stated, point in the same direction. The sternum, girdles, and all the limb bones, the hand and foot with the divergent pollex and hallux, the tarsus, especially the astragalus, offer additional evidence of relationship. Finally, in *Tupaia* there are twelve or thirteen dorsals, six or seven lumbars, and three sacrals, exactly as in certain Lemurs.

I think this body of evidence is sufficient to indicate that even although Tupaiids and Lemuroids may have separated very early, and even although many of the similarities may have developed under the stimulus of similar arboreal habits, yet there is a real genetic relationship between the two groups.

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[4] Address to the Anthropological Section. Brit. Assoc. Adv. Sci., Section A. Dundee, 1912, pp. 1-24.

[5] Gregory; Op. cit., pp. 321-322.

Ptilocercus is somewhat more lemur-like than *Tupaia* in its skull and dentition. The malar and jaw are stouter; the tendency toward diprotodonty more pronounced; the molars more bunodont, with incipient hypocone-cingula. I was, however, surprised to find that in its post-cranial skeleton *Ptilocercus* is on the whole less lemur-like than *Tupaia.* It has fourteen dorsals and five lumbars,[6] its ribs are broad and flat, the thorax and sternum are shorter, the dorsal vertebræ have low spines, and the parapophyses of the lumbars are but feebly developed. The limbs are less elongate, the ilium rodlike rather than spatulate, the pubis and ischium small, and the pubic symphysis very short; whereas it is long in *Tupaia,* Macroscelidæ, and Lemurs. The scapula is broader than in *Tupaia,* the humerus less elongate, the supinator crest more pronounced, the entocondyle and entepicondylar foramen are prominent, and the capitellum globular. The hallux and pollex seem to be capable of marked divergence. All this appears to indicate that *Ptilocercus* is less agile and squirrel-like, perhaps more Marmosa-like, in habits than *Tupaia;* also that many of the lemurine characters of *Tupaia* may have been developed independently.

Entomolestes an Eocene Tupaiid

One of the American Museum Expeditions to the Bridger Basin secured there a minute lower jaw, which was described by Matthew[7] in 1909 and named by him *Entomolestes grangeri* in honor of its discoverer. Doctor Matthew noted the resemblance of this jaw to that of *Tupaia,* but owing to lack of adequate material for comparison, he left the genus incertæ sedis as to family, merely referring it to the Insectivora. The subsequent acquisition by the museum of skeletons representing the principal types of recent Insectivores has led me to compare this precious relic with the jaws of recent and fossil Insectivores, Bats, and Primates of many families. This comparison has brought into clear view the close agreement in essentials of *Entomolestes* with the Tupaiidæ, especially the small *Tupaia modesta;* so that I feel reasonably safe in stating that in the Bridger Eocene of North America there lived a very primitive representative of the Oriental Tupaiidæ.

From certain indications I infer that there was a small first incisor;

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[6] The complete vertebral formula of *Ptilocercus* is: C7, D14, L5, Cd. 33.

[7] The Carnivora and Insectivora of the Bridger Basin, Middle Eocene. Mem. Amer. Mus. Nat. Hist., vol. 9, part 6, 1909.

the alveoli for the second and third incisors, for the canine, premolar$_1$ and premolar$_2$ are well preserved; the incisors were gently procumbent; the canine was small, single-fanged, erect, and located well back on the side of the jaw; p_1, p_2 were small, very simple teeth; p_3, p_4, and the three molars, all perfectly preserved, much resemble those in *Tupaia*, and differ markedly from those in *Galerix*, Lepticids, and other Eocene Insectivores.

Entomolestes is considerably more primitive than either *Tupaia* or *Ptilocercus* in the following characters: First, in its very minute size, the jaw being no bigger than that of a shrew; secondly, the jaw retains the complete Eutherian dentition, the formula being 3.1.4.3, whereas the modern Tupaiids have lost $p\frac{1}{1}$; third, the tendency toward diprotodonty and reduction of the canine, so prominent in *Ptilocercus*, is here only suggested; fourth, the symphysial region is shallower and the ramus more curved below—characters seen in Jurassic Insectivores; fifth, the molars had lower crowns than in *Tupaia*; sixth, the cingulum at the anteroexternal base of the trigonid, vestiges of which are retained in *Ptilocercus*, was pronounced; seventh, the teeth were in continuous series as in *Ptilocercus*, whereas in *Tupaia* the canine and anterior premolars have become irregularly spaced. The sole point in which the *Entomolestes* jaw appears to be aberrant is in the slightly reduced size of m_3.

Thus *Entomolestes* carries the Tupaiidæ back to a primitive Middle Eocene type, the teeth of which, as Dr. Matthew[8] noted, were partly transitional to the type shown in Apatemyidæ, Mixodectidæ, and primitive Lemuroidea. But from all of these it is distinguished by retaining the complete Eutherian dental formula and by having the talonids of the lower molars not expanded; it is also without a hypoconulid on m_3.

NOTHARCTUS AN EOCENE LEMUR

In the same formation, the Bridger, along with this very primitive Tupaiid the American Museum Expeditions found several incomplete skeletons of one of the most primitive known Primates, the genus *Notharctus*. This material is of signal importance in the problem of Primate genealogy, and it has been generously placed in my hands for description by Doctor Matthew.

If the postcranial skeleton of *Notharctus* had been well known in Cope's time, without admixture of foreign material, much confusion would have been saved. If the limbs and vertebræ had been known before the skull, the genus would undoubtedly have been placed in the family Lemuridæ and even in the subfamily Lemurinæ. The metapodials, astragalus and calcaneum, pelvis, femur, tibia, humerus, forearm, vertebræ, and all other parts preserved are practically identical with those of *Lemur.* Every process, rugosity, and curve in the *Notharctus* bones finds its evident homologue in *Lemur,* so that the myology of the two must have been almost identical. Only the Eocene genus was slightly more primitive, in that the limbs are less elongate.

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[8] Op. cit., p. 537.

The skull of *Notharctus* has a much smaller brain-case, smaller auditory bullæ, and a far less specialized dentition. The incisors, canines, and anterior premolars are of primitive type and have not assumed the aberrant and highly characteristic lemurid form. Because its front teeth lack the lemurid modification and because the supposed course of the entocarotid artery and certain details of the lacrimal are not the same as in Lemurs, Doctor Wortmann[9] concluded that *Notharctus* was not an ancestral Lemur; but it now appears probable that these differences from Lemurs are merely primitive rather than aberrant characters. So far as I have yet observed, there is only one important character which excludes *Notharctus* from direct ancestry to the Lemurs. The upper molars in becoming incipiently quadritubercular have departed from the more tritubercular type preserved in the ancestral *Pelycodus* of the Wasatch and Wind River. *Pelycodus* is nearer to the ancestors of *Lemur;* while the allied *Pronycticebus* of the French Eocene is held by Grandidier[10] to be ancestral to the common Loris (*Nycticebus*). A phylogenetic or vertical classification would include *Pelycodus* and *Notharctus* in the Lemuridæ; but a "horizontal" classification, marking stages of evolution, would include *Notharctus* in the Adapidæ, as has been done by Schlosser.[11] An examination of skulls, teeth, and limb bones of *Adapis* and *Notharctus* indicates that *Adapis* is merely a specialized and aberrant collateral descendant of *Notharctus,* as held by Schlosser.

The postcranial skeleton of *Notharctus* is more primitive than that of any Platyrhine or Catarhine; *Notharctus* also retains the right number and kind of incisors, canines, and premolars for an ancestral monkey of either grand division. However, the occurrence of numerous short-jawed, large-brained Primates in the Wasatch with normal incisors, small canines, tritubercular molars, and reduced premolars suggests the rise of *Tarsius* and the Anthropoidea from the neighborhood of the Anaptomorphidæ, as maintained by Schlosser.

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[9] Eocene mammalia in the Marsh collection, Peabody Museum. Part ii, Primates. Amer. Jour. Sci., vol. 15, p. 410.

[10] Les Lemuriens disparus. . . . Nouv. Archiv. du Mus. 4e Ser., Tome vii, 1905, pp. 28-30.

[11] Zittels Grundzüge der Paläontologie. II. Abt. Vertebrata, 1911, p. 547.

CONCLUSIONS

To recapitulate, present evidence favors the following conclusions:

(1) That in the Bridger Eocene there already existed primitive Tupaiid Insectivores (*Entomolestes*) and primitive lemur-like Primates; and these, while less widely separated than their modern representatives, were even at that time referable to distinct orders.

(2) The fauna of the Wasatch, with its numerous highly modernized types, such as *Anaptomorphus,* proves that we are witnessing rather the noontime than the dawn of Placental Mammals. The marked structural gap even in the Eocene between Tupaiids and Primates does not, I think, constitute a serious objection to the ultimate derivation of the Primates from *Entomolestes*-like ancestors of the late Mesozoic. The Primates give evidence of derivation from very small mammals, with a dental formula of $\frac{3.1.4.3.}{3.1.4.3.}$, animals with simple non-carnassial premolars and tritubercular molars; and such mammals could only have been Insectivores of some sort.

(3) It seems quite likely that many of the lemur-like features of *Tupaia,* such as the large brain-case, ringed orbits, enlarged lumbar parapophyses and the like, may have been developed independently after the separation of the Primates took place.

(4) That in spite of their very ancient divergence the Primates are more nearly allied to the Tupaiids than to any other existing group.

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PETROLEUM FIELDS OF NORTHEASTERN MEXICO BETWEEN THE TAMESI AND TUXPAN RIVERS[1]

BY I. C. WHITE

(Read before the Society December 30, 1912)

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LOCATION OF THE FIELDS

The region described in this paper lies along the Gulf coast of the Republic of Mexico in the States of Tamaulipas, Vera Cruz, and San Luis Potosi. The author visited this district during November and December, 1911, and was afforded every facility for travel by the officers of the Mexican Petroleum Company, Limited, of Delaware, on rail, steamer, and horse through several hundred miles of jungle, seeing and examining a large number of petroleum developments and seepages. For a portion of the trip the party was accompanied by Señor Ezequiel Ordonez, the distinguished Mexican geologist and Fellow of this Society, whose intimate knowledge of Mexican geology, and especially of the structural conditions in the petroleum fields of Mexico, proved of great value and assistance in the cursory study undertaken. The locations of the principal oil developments along the Gulf coast of northeastern Mexico, as well as many of the seepages, are shown on this blue-print map, furnished the writer through the courtesy of Herbert G. Wylie, of Ebano, general manager of the Mexican Petroleum Company's interests in the Republic and one of the ablest business men in the petroleum world.

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[1] Manuscript received by the Secretary of the Society December 31, 1912.

GEOLOGY OF THE MEXICAN PETROLEUM FIELDS

It has long been recognized, both by geologists and practical petroleum operators who lay no claims to geological knowledge, that *disturbance* of the sedimentary beds, so as to tilt them out of the horizontal position to a greater or lesser extent, is an essential factor in the accumulation of oil and gas into pools or deposits of commercial value. In the Appalachian fields of Pennsylvania, West Virginia, Ohio, Kentucky, etcetera, these disturbances partake of the character of anticlinal and synclinal waves of small amplitude practically parallel to and made by the same orogenic movements which created the vast arches and folds in the rocks of the Alleghany Mountain region. The same structural features hold true for the oil regions of Indiana, Illinois, Oklahoma, Colorado, Wyoming, California, etcetera, and also hold true for the other great oil fields of the world, as in Russia, Rumania, and India. Along the Gulf coast of Texas, however, as illustrated at Beaumont, other factors of sedimentary disturbance than mountain-made folds in the earth's sedimentary crust come into play, and we get a series of domes where the rocks dip away from the highest point in every direction, or in a quaquaversal manner, instead of the anticlinal, synclinal, or monoclinal features of geologic structure so common in the Appalachian oil and gas fields. The formation of these dome structures in the rocks of Texas and Louisiana is explained in a plausible way by Prof. Gilbert D. Harris, former State Geologist of Louisiana, as due to the immense lifting force generated in the crystallization of salt in the vast beds of this mineral which underlie the coastal plains region of the States in question.

In passing southwestward from Texas into the Republic of Mexico a *third* agency of geologic disturbance of the sedimentary beds becomes operative, namely, the uplifting effects of volcanic dikes, necks, laccolites, and other forms of igneous activity in tilting the sedimentary beds into domelike structures, fracturing and faulting even the close-grained shales and sending tongues of porous lava into them in such a manner as to make large reservoir spaces where none previously existed, and permitting the petroleum and its accompanying natural gas to leak upwards to the surface as seepages very often in immediate contact with the basaltic lava, and sometimes through joints of the lava itself, as at Moralillo. These intrusions of volcanic materials have accomplished in the Mexican Gulf coast fields what orogenic movements and crystalline forces have done in creating disturbance and tilting of sedimentary beds in the oil and gas fields of the United States, so as to permit the small quantities of petroleum, gas, and water present in most undisturbed sedimentaries to segregate and accumulate into reservoirs of commercial quantity and value. Señor Ezequiel Ordonez, who joined our party at Monterey, accompanying it as far as Casiano, and who communicated to the writer freely the results of his studies of the Mexican oil fields, believes that these intrusions of volcanic matter in the shape of domes, ridges, etcetera, along the Gulf coast are of quite recent date, geologically speaking, and his views would appear to be confirmed by the topography of the basaltic domes, as also by the newness and character of the principal seepages, since the asphaltic residua, even in the most active vents, have not accumulated to a depth of more than 20 to 25 feet. Señor Ordonez also thinks that in all the shallower wells which do not penetrate to the Tamasopa limestones, the parent strata of the petroleum, that the principal reservoirs have been created by the intrusion of volcanic debris in a porous or vesicular condition horizontally into the shales, thus fracturing them and forming additional reservoir space.

Age of the Oil-bearing Strata

There can be practically no doubt that the mother rock or main reservoir of petroleum along the Gulf coast of Mexico is the Tamasopa limestone of the Mexican Cretaceous terranes, supposed to be several thousand feet thick, and which, rising suddenly out of the plain, makes a great wall of limestone, the first rock terrace of sedimentaries, 1,500 to 2,000 feet high, which we encounter in going from the Gulf coast westward toward the region of the great Mexican plateau. On above the Tamasopa limestone there comes in a series of flaggy and shelly limestone beds interstratified with marly shales, the whole being known as the San Felipe series, with a thickness of 400 to 500 feet. The limestones of this series appear to hold oil at times, but the reservoir may be from fractures and dikes of igneous intrusions. Succeeding the San Felipe series come the Mendez marls and shales, with a thickness of 2,000 to 3,000 feet, which make an excellent cover to protect the underlying oil deposits from all escaping to the surface through the numerous faults and fractures which the extrusion of basaltic domes and dikes has effected. These two formations—San Felipe and Mendez—Dr. C. W. Hayes, the new general manager of the Pierson oil interests in Mexico, thinks are of the same age as the Laramie beds of the United States, namely, intermediate between the true Cretaceous and Tertiary.

Above the Mendez beds come Tertiary sandstones and shales several hundred feet thick, along with Quaternary unconsolidated deposits, all dipping toward the Gulf coast, together with the underlying Mendez, San Felipe, and Tamasopa beds, so that here in Mexico we appear to have in ideal form the three conditions under which petroleum and natural gas can accumulate into pools of commercial value, namely:

(1) Sedimentary beds tilted into domes, anticlinals, monoclinals, and other forms of relief.

(2) Very porous rocks and large reservoirs, either in the Tamasopa limestone, with much crystalline and solution cavities, as indicated by specimens of limestone thrown up by the oil and gas flows, and also much reservoir space in the Mendez and San Felipe beds through intrusion of dikes and sills of perhaps vesicular basalt breaking and fracturing the sedimentaries and adding to the reservoir space in the shales through pulsating movements of these intruded igneous masses during periods of active eruptions, as believed by Ordonez.

(3) An *impermeable cover*, San Felipe and Mendez beds, with much clay, marl, and close-grained shales, and only permitting the oil and gas to get up to the surface in small quantities along narrow fissures, faults, and crevices, where fractured by the upthrust of basaltic dikes and batholites.

That the Tamasopa, or "basalt limestone" of the drillers, is the real source of the petroleum in these Mexican fields appears to be amply demonstrated by the fact that all the large gushers, like Nos. 6 and 7 Casiano and the famous Potrero del Llano well, obtain their oil in the top of this great limestone formation.

RECORDS OF THE CASIANO WELLS

The character of the beds overlying the Tamasopa limestone is shown by the following records of Casiano wells Nos. 6 and 7 and some from near Ebano:

Juan Casiano Well No. 6

Started drilling April 7, 1910

Top Feet	In.	
0		Yellow clay.
35		Gray shale.
60		Spudding bit unscrewed.
76	7	Landed 16-inch casing.
250		Put in $12\frac{1}{2}$-inch casing.
315		Bad hole; filled hole up to 95 feet April 26.
270		Bad hole; filled hole up to 235 feet; hole straightened up May 12.

Juan Casiano Well No. 6—Continued

Feet	In.	
650		12½-inch collar bound; pulled casing 15 joints to free it.
890		Cable broke (fishing job).
993		Shell.
993		Landed 12½-inch casing May 28.
995		Showing of oil.
1,035		Showing of oil.
1,880		Showing of oil.
1,960		Showing of oil and gas.
2,100		Mud that freezes the pipe.
2,116	9	10-inch casing froze July 1, 1910.
2,150		Tools stuck; line came out of socket.
2,155		Brown shale.
2,160		Showing of oil.
2,173		Gray shale.
2,258		Brown shale.
2,287		Landed 8-inch casing.
2,316		Sandy shell.
2,319		Light blue shale, showing of mica.
2,324		Gray sandy shell.
2,339		Limestone.
2,363		Oil, July 26, 1910.

Shut in after producing about 150,000 barrels of oil in 15 days and increasing from 8,000 barrels the first day to over 14,000 on the last, or September 10.

Juan Casiano Well No. 7

Started drilling June 18, 1910

Top Feet	In.	
0		Yellow clay.
35		Gray shale.
76		Landed the 16-inch casing.
100		Lime shell.
102		Gray shale.
213		Put in 12½-inch casing.
322		Cable broke (fishing job).
861		Shell.
863		Gray shale.
1,011		Landed 12½-inch casing July 17, 1910.
1,073		Sandy shell.
1,076		Gray shale.
1,110		Sandy shell.
1,112		Gray shale.
1,125		Black sand shell (underreamed).
1,137		Gray shale.
1,170		Sandy shell.

Juan Casiano Well No. 7—Continued

Feet	In.	
1,175		Gray shale.
1,294		Shell (underreamed).
1,296		Gray shale.
1,342		Sandy shell (underreamed).
1,348		Gray shale.
1,484		Shelly.
1,508		Gray shale.
1,538		Shelly.
1,556		Gray shale.
1,782		Cable broke (fishing job).
1,992		Brown shale.
2,040		Gray shale.
2,070		Light blue shale, showing of mica.
2,078		Gray shale.
2,106	8	Landed 10-inch casing.
2,107		Lime.
2,112		Oil, September 11, 1910.

Production to April 16, 1913, 20,697,000 barrels, and still flowing 22,000 barrels daily under a pressure of 281 pounds.

Laguna No. 2

Top Feet	
20	Clay.
45	Shale.
65	Shale.
85	Slate.
105	Shale.
165	Shale.
175	Shells.
190	Hard shells.
210	Slate.
230	Shale.
270	Shale.
310	Shale.
620	Shale.
645	Mud.
740	Shale.
770	Slate.
785	Shale.
795	Slate.
805	Shale.
865	Shale.
890	Shale.
900	Slate.
950	Slate.
975	Slate.
1,005	Slate.
1,040	Shale.
1,135	Slate.
1,150	Slate.
1,165	Hard slate.
1,185	Shells and mud.
1,215	Shells.
1,230	Shale.
1,270	Shale.
1,290	Shells.
1,310	Struck some oil.
1,325	Shale.
1,330	Rock.
1,460	Shale.
1,490	Lime and shale.
1,500	Limestone.
1,505	Shale.
1,510	Limestone.
1,520	Lime rock.
1,544	Well flowing October 29, 1906.

Laguna No. 3

Top Feet	
10	Doby shale.
45	Yellow clay.
75	Shale.
95	Blue shale.
130	Shale.
175	Gray shale.
197	Shale.
219	Gray shale.
242	Shale.
272	Gray shale.
304	Shale.
334	Gray shale.
355	Gray shale.
385	Gray shale.
425	Gray shale.
475	Brown shale.
515	Gray shale.
695	Gray shale.
780	Hard gray shale.
820	Gray shale.
855	Gray shale.
910	Gray shale.
980	Gray shale.
1,035	Gray shale.
1,155	Gray shale.
1,158	Blue shale.
Feet	
1,215	Gray shale.
1,295	Gray shale.
1,360	Gray shale.
1,424	Gray shale.
1,435	Gray shale.
1,495	Gray rock.
1,502	Gray shale.
1,600	Hard.
1,620	Gray shale.
1,685	Gray shale.
1,710	Hard shells.
1,760	Shells and shale.
1,820	Gray rock.
1,860	White shale.
1,885	Oil and gas.
1,935	More oil and gas.
1,940	White shale.
1,974	Light shale.
1,987	White shale.
2,074–2,088	Lime.
2,090	White shale.
2,180–2,191	Lime.
2,225	Lime.
2,245	Well flowing October 19, 1907.

Laguna No. 17

Top Feet	
1–63	Blue mud.
142	Light shale.
148	Blue slate.
189	Light shale.
241	Light shale.
330	Light shale.
404	Pink rock.
419	Blue slate.
450	Pink rock.
490	Pink rock.
573	Light shale.
629	Blue shale.
686	Shells.
721	Pink slate.
804	Light shale.
841	Blue slate.
880	Light shale.
965	Blue shale.
1,009	Blue shale.
1,028	Blue shale.
Feet	
1,058	Blue shale.
1,255	Light shale.
1,305	Light shale.
1,355	Light shale.
1,426	Light shale.
1,448	Limestone.
1,479	Blue shale.
1,507	Limestone.
1,533	Lime shells.
1,566	Light shale.
1,614	Lime.
1,638	Blue shale.
1,661	Lime shale and shells.
1,692	Lime shale and shells.
1,720	Light shale.
1,742	Lime.
1,754	Shale.
1,766	Shale and shells.
1,766	Hard blue rock.
1,780	Well flowing April 30, 1909.

La Pez No. 1

Top Feet		Feet	
300–330	Hard.	1,005	Shale.
480	Shale.	1,085	Shale.
535	Shale.	1,120	Shale.
570	Shale.	1,150	Shale.
620	Shale.	1,160	Shale, with little oil.
645	Shale.	1,195	Shale.
705	Shale.	1,200	Hard shale.
750	Shale.	1,300	Shale.
790	Shale.	1,385	Struck oil.
835	Shale.	1,395–1,445	Shale and oil.
880	Shale.	1,650	Well flowing since April 3, 1904.
935	Shale.		

La Pez No. 4

Top Feet		Feet	
30	"Doby."	750	Shale.
48	White shale.	765	Red rock.
85	White shale.	795	Shale.
127	Blue shale.	820	Shale.
157	Blue shale.	870	Shale.
170	Shale.	920	Shale.
210	Blue shale.	990	Shale.
305	Gray shale.	1,070	Shale.
389	Blue shale.	1,190	Shale.
400	Brown sandy shale.	1,250	Shale.
441	Sandy shale.	1,315	Shale.
456	Red shale.	1,360	Blue shale.
480	Little showing of oil.	1,415	Shale.
615	Shale.	1,440	Shale.
640	Blue shale.	1,465	Shale and sand.
662	Shale.	1,500	Shale and sand.
682	Shale.	1,540	Shale and sand.
688	Shale.	1,650	Shale Shale up to
700	Shale.	2,010	Well flowing January 11, 1906.
745	Red rock.		

La Pez No. 6

1908	Feet		Feet	Formation
November 20	28	to	40	Soft white shale.
21	40	"	95	Soft white shale.
22	95	"	150	White shale.
23	150	"	235	White shale.
24	235	"	300	Soft brown shale.
26	300	"	360	Soft brown shale.
27	360	"	372	Soft white shale.
29	372	"	447	Brown shale.
30	447	"	625	Brown shale.

La Pez No. 6—Continued

1908		Feet		Feet	Formation
December	1	625	to	735	White shale.
	3	735	"	745	White shale.
	4	945	"	1,058	Shells and slate.
	5	1,058	"	1,135	Hard white shale.
	6	1,135	"	1,200	White shale.
	7	1,200	"	1,265	White shale.
	8	1,265	"	1,300	White shale.
	12	1,300	"	1,350	White shale.
	13	1,350	"	1,425	Lime, shells, and slate.
	14	1,425	"	1,470	White lime shells.
	15	1,470	"	1,518	Hard lime shells and white slate.
	16	1,518	"	1,543	Hard white shale.
	17	1,543	"	1,563	Hard shells and slate.
	19	1,563	"	1,570	900 feet of oil in hole.
	22	1,570	"	1,595	Hard lime.
	23	1,595	"	1,645	White slate and shells.
	24	1,645	"	1,680	Hard lime shells.
	25	1,680	"	1,702	Lime shells.
	26	1,702	"	1,738	Hard white shale.
	27	1,738	"	1,751	Hard lime shells.
	28	1,751	"	1,764	Hard shells.
	30	1,764	"	1,802	Lime shells and slate.
	31	1,802	"	1,832	Hard shells and slate.
1909.					
January	1	1,832	"	1,866	Slate and shells.
	3	1,866	"	1,886	Well flowing.

Chijol No. 4

Top Feet	
30	Surface.
52	Clay.
57	Hard gray shale.
75	Lime.
105	White shale.
132	White shale.
144	White shale.
154	Red slate.
204	White shale.
320	Gray shale.
360	Blue slate.
385	Gray shale.
	Two-foot crevice.
400	White slate.
445	White slate.
488	White lime.
508	Crevice with oil.
513	White lime.
Feet	
566	White shale.
600	White shale.
635	Blue slate.
650	Blue slate.
660	White slate.
	Crevice with oil.
673	White shale.
	Crevice.
690	White slate.
695	Gas crevice.
725	White shale.
772	White shale.
797	White shale.
895	White shale.
920	Gray shale.
940	White shale.
983	Blue shale.
1,024	White shale.

Chijol No. 4—Continued

Feet	
1,176	White shale.
1,206	White shale.
1,270	White shale.
1,307	White shale.
1,373	Hard shale.
1,400	White slate.
1,407	White slate.
1,410	Crevice with oil.
1,444	Oil, very hard.
1,516	Hard shells.
1,524	Very hard.
	Pumping oil.
1,567	With oil (white shale).
1,597	White shale.
1,611	Gray shale.
1,628	Struck more oil.
1,633	Hard shale.
1,640	Hole filling up.
1,645	Hard.
1,655	Well flowing November 12, 1909.
1,665	Hard.
1,693	White shale.
1,741	Oil and gas, January 19, 1910.

Chijol No. 5

Feet	Top
25	Yellow clay.
30	Gray shale.
35–45	Hard rock.
52	Black shale.
70	Black hard rock.
85	Light hard shale.
103	Hard gray rock.
107	Brown shale.
116	Hard shell.
119	Lava rock (basalt).
123	Crevice with oil.
137	Brown sandy shale.
205	Shale.
223	Brown shale.
230	More oil.
248	Very hard.
256	Hard shell.
337	Very hard shell.
344	Hard rock.
348	Fine shale.
374	Hard shell.
520	Hard shell.
785	Very hard.
800	White shell (caving).
825	Shale.
842	Gray shale.
844	Soft shale.
868	Light shale.
918	Gray shale.
995	White shale.
1,000	Lime rock.
1,002	Hard.
1,032	Hard shale.
1,100	Hard.
1,102	Soft.
1,104	Hard.
1,124	Light shale.
1,155	Hard shale.
1,202	Limestone.
1,217	Hard shale.
1,263	Light shale.
1,310	Light shale.
1,370	Light shale.
1,415	Hard shale.
1,433	Soft shale.
	Oil.
1,468	Gray shale.
1,500	Light shale.
1,530	Gray shale.
1,639	Gray shale.
1,664	White shells.
1,735	Hard.
1,741	Soft.
1,766	Light shale.
1,843	Hard gray rock.
1,866	Shale and shells.
1,900	Blue shell.
1,944	Soft shale.
1,993	Hard.
2,019	Shale and shells.
2,034	Hard.
2,044	Hard.
2,069	Hard shale.
2,092	Hard shale.
2,012	Well flowing March 12, 1911.

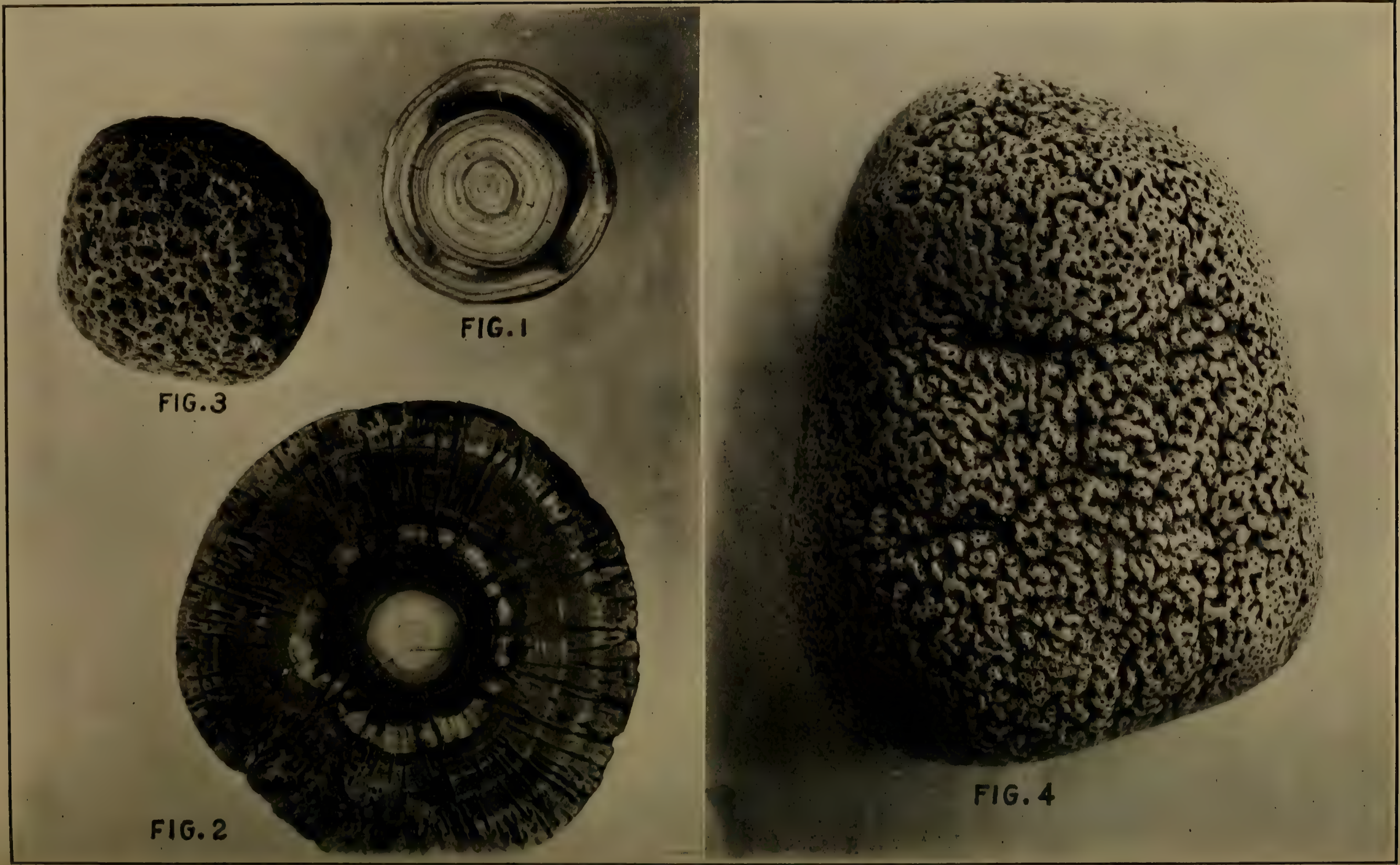


FIG. 1

FIG. 3

FIG. 2

FIG. 4

CONCRETIONS FROM MEXICAN OIL WELLS

These several records give a fair idea of the lithological character of the sediments for, say, 2,200 feet above the Tamasopa limestone. There appear to be two horizons marked by red or pink-colored shales, the higher of which is seen cropping at the surface near the large concrete reservoir at Ebano, and also in Chapopote Gulch, while the lower red horizon is shown in Pez No. 4 at a depth of 745 feet. This latter horizon was also noted in Laguna No. 17 of the Ebano field at a depth of 721 feet.

Well No. 5, at Chijol, near Ebano, had a peculiar experience. It was started at a large seepage and struck basalt at 50 feet. It was then moved several feet, but again struck the basalt, and was moved a few more feet to a third location, where the dike was struck at 116 feet, which, after great difficulty, the drill finally penetrated, 21 feet lower, and entered the shales as shown in the drillers' record of No. 5, Chijol.

These records also reveal the fact that oil can be found at most any depth even in the shales, wherever the drill strikes a fissure, fault, or porous layer in its descent.

The character of the "oil sand" or reservoir rock was not observed, as none of it had been preserved; but Doctor Hayes says that fragments of limestone thrown out of the great Potrero del Llano well give evidence of much erosion or solution cavities.

An interesting feature connected with those wells flowing hot salt water is the formation of limestone balls or spheres filled with a regular lace-work of branching cavities very much resembling coralline growth. Doctor Hayes attributes the formation of these spheres to the lessened solubility of the gradually cooling water on its passage up the oil-well vents. Many of these spheres from ½ inch to 5 inches or more in diameter have been thrown out of the Dos Bocas hot water well, as also from La Pez No. 6. The deposition of the lime probably begins around some nucleus of foreign matter, but Dr. Geo. P. Merrill, of the National Museum, who examined several of these balls, could find but little evidence of any distinct nucleus. The following notes and illustrations of these concretions, kindly made for this paper by Doctor Merrill, will prove of much interest:

"I have examined the concretions from the Mexican oil wells with a good deal of interest, and have to state as follows:

"The general external form, as readily noted, is either spherical or oval, the surface being at times nearly smooth or again containing numerous perforations of a millimeter or more in diameter. Cut through the center, they show concentric layers of calcium carbonate, some of which are nearly white in color and very pure, and others so stained with bituminous matter as to be almost black (plate 5, figures 1 to 3). The bituminous matter sometimes impregnates, quite uniformly, various layers of the concretion, but is more commonly contained in elongated cavities, from 1 to 10 or more millimeters in length, arranged with their longer axes radiating from the center toward the circumference like spokes of a wheel (plate 10, figure 3). These, one might infer, were formed by the elimination of the petroleum from the fluid in which the concretion was forming. The perforations on the outer shells of some of the concretions are evidently due to the fact that the cavities had not as yet become sealed by the further deposition of lime (plate 5, figure 4). Certain irregular forms like that shown in plate 5, lgure 3, have, however, the appearance of having been irregularly corroded since the concretion-forming process ceased, whereby a part of the material has been redissolved and the cavity walls etched and greatly enlarged. These latter forms, it should be stated, are so heavily charged throughout with petroleum as to be almost black from core to circumference.

"I find in but two cases any trace of a foreign body which would serve as a nucleus, and in these cases the material is a mere pinhead of ferruginous and clayey material. In all others the material is lime carbonate throughout, with the exception of the bitumen, and goes readily into solution. This lack of an appreciable nucleus is not surprising, in the present state of our knowledge of concretionary formation.

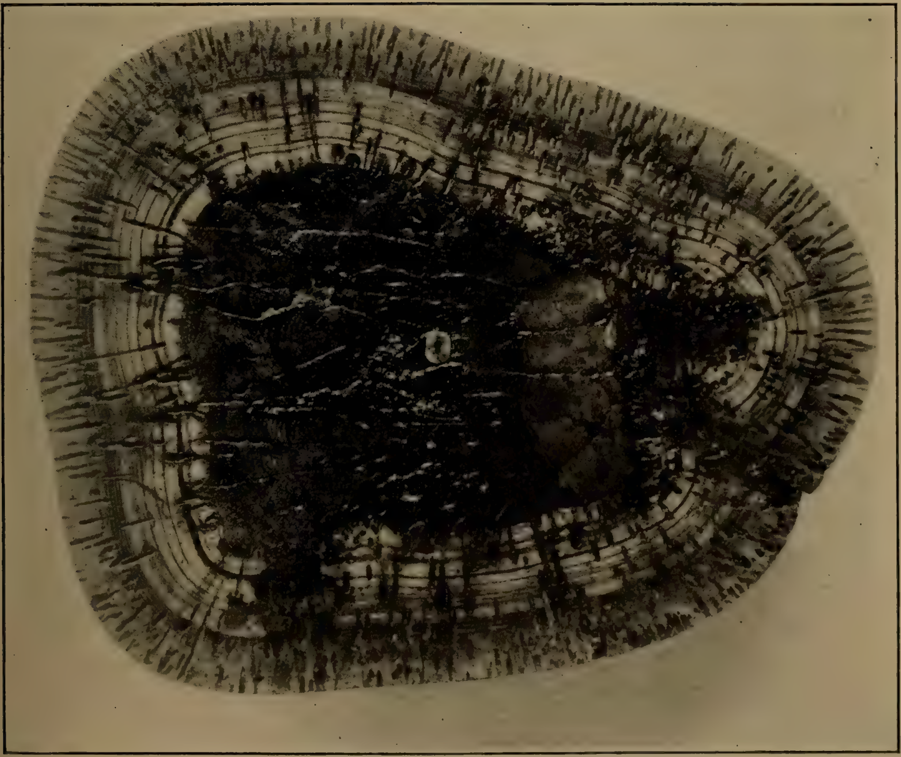
"Dr. T. Wayland Vaughan has called my attention to the work of G. Linck and others, since corroborated by himself through observations on the formation of the oolitic limestone on the Bahamas, where the lime is first thrown down chemically by the increasing alkalinity of the water caused by bacterial action. Though apparently thrown down as an amorphous powder, it soon begins to gather into the form of minute, almost microscopic concretions without a trace of nucleal material—indeed, in water in which no foreign material is present.

"Under the microscope these Mexican concretions show simply concentric layers of radiating lime carbonate, the layers varying somewhat in degree of crystallization, but the material in all cases, so far as the cobalt nitrate test can be relied upon, being calcite and not aragonite.

"Concerning the conditions under which they are formed you are better informed than am I. The rate of growth is evidently very rapid; otherwise the bituminous material would be excluded. It is, however, evident that they are not all formed in one continuous process, as on breaking the material falls away in shell-like forms showing surfaces coated with bitumen, and in one case, as shown in plate 6, there is in the center a small concretion of only 3 or 4 millimeters in diameter, while toward the smaller end of the oval are five starting points from which crystallization radiated upward for a little more than half the length of the specimen. At that point crystallization seems to have stopped and then begun again at three different points, and continued upward for a maximum distance of a little over 25 millimeters. Then the process seems to have stopped again, and finally concluded with the formation of concentric layers about the whole mass, which was continued until the present size and form were assumed."

CHARACTER OF THE OIL

The petroleum found in the region examined has an asphalt base and varies in gravity, Baumé, from 10½° to 12° in the Ebano district to 21°



CROSS-SECTION OF CONCRETION FROM MEXICAN OIL WELL

at Casiano, and is therefore a typical fuel oil. The heavier oil occurring at Ebano is specially valuable for the manufacture of a high-grade asphalt, and this is being done at the Ebano refinery, where the yield of this product is about 45 per cent, the 55 per cent of distillates, after 3 to 5 per cent of 55° to 57° gasoline is distilled off, being sold to the Waters Pierce refinery or used, as fuel oil.

Mr. W. L. Garrett, the oil expert who examined the Mexican oil fields for the Mellon interests of Pittsburgh, Pennsylvania, during March, 1911, collected two samples of oil from Casiano well No. 7, and these, as analyzed by the Gulf Refinery and reported by Mr. Garrett, gave the following results:

Huasteca Oil

Casiano Field, Well No. 7

Sample No. 1

Gravity, 19.4° Baumé.
Flash, 80.
Viscosity, 450 B. O. T.
Sulphur, 1.93 per cent.
Pour, 0.
B. S., 3 per cent.
B. T. U., per pound, 19,124.

Fractional Distillation

Temperature	Per cent	Gravity
Over at 259°–385°	10	58.7
Over at 385°–493°	10	45.9
Over at 493°–500°	1	
Total:		
Distillates	21	51.5
Residue	78	13.5; pour, 40
Loss	1	
	100	

Sample No. 2

Gravity, 19.3° Baumé.
Flash, 96.
Viscosity, 500 B. O. T.
Sulphur, 2.08 per cent.
Pour, 0.
B. S., 2 per cent.
B. T. U., per pound, 19,160.

Fractional Distillation

Temperature.	Per cent.	Gravity.
Over at 244°–400°	10	57.8
Over at 400°–493°	10.0	45.1
Over at 493°–500°	0.6	
Total:		
Distillates	20.6	50.8
Residue	78.5	13.4
Loss	.9	
	100.0	

The oil contains sulphuretted hydrogen as well as carbon disulphide, and hence the gases which issue with the oil are very poisonous, several Mexicans having been asphyxiated when breathing them to the exclusion of air. These sulphur compounds, however, do not interfere with the use of the oil for fuel, since the B. T. U. is very high (19,124 and 19,160), and in refining and in the manufacture of gas for illuminating purposes the sulphur can be readily removed by well-known processes. This oil is very successfully used for the manufacture of illuminating gas in the city of Mexico, and when used for making steam at the gas works in question an evaporative capacity of 16 pounds of water to every pound of oil is the regular result, thus giving a very high rate of efficiency for steam and general fuel purposes and insuring a constantly enlarging market wherever coal commands a fair price, since 3½ barrels of this oil equals in heating value a ton of good coal. The oil is very dark, and at Ebano has a temperature of 105° Fahrenheit, 110° at Casiano, and 132° at Potrero del Llano, as reported by Mr. Weaver, the superintendent in charge (although Dr. David T. Day, in "Petroleum Statistics for 1910," reports the temperature of the oil at 147°).

Production of the Wells

The first well to produce oil in large quantities on the properties of the Mexican Petroleum Company, Limited, is known as La Pez No. 1, about 2 miles from Ebano Hill. It came in as a flowing well April 3, 1904, and still continues to flow at the rate of 300 to 1,000 barrels daily. The following tabular statement taken from the books of the Mexican and Huasteca Petroleum companies, both of which are owned by the Mexican Petroleum Company, Limited, of Delaware, gives the date of completion and total production to the date given of each producing well on all of the properties:

Statement of Production of Ebano and Casiano Wells

Well	Barrels
Pez No. 1, from April 3, 1904, to November 30, 1911	3,178,963
Pez No. 3, from October 24, 1905, to September 5, 1911	4,342
Pez No. 4, from July 20, 1906, to December 21, 1911	1,150,194
Pez No. 5, from April 1, 1906, to November 30, 1911	366,551
Pez No. 6, from January 2, 1909, to November 30, 1911	1,323,837
Pez No. 7, from December 1, 1910, to November 30, 1911	20,638
Laguna No. 2, from November 7, 1906, to November 30, 1911	750,240
Laguna No. 3, from April 2, 1907, to November 30, 1911	894,597
Laguna No. 4, from April 22, 1908, to September 6, 1911	237,571
Laguna No. 5, from May 17, 1909, to January 8, 1911	92,810
Laguna No. 7, from June 20, 1908, to August 30, 1911	930,858
Laguna No. 10, from July 9, 1908, to August 30, 1911	156,942

Statement of Production of Ebano and Casiano Wells—Continued

Well	Barrels
Laguna No. 11, from September 17, 1908, to November 30, 1911	131,426
Laguna No. 14, from February 2, 1909, to November 30, 1911	321,691
Laguna No. 17, from May 19, 1909, to November 30, 1911	71,512
Laguna No. 19, from May 17, 1909 to January 8, 1911	90,160
Laguna No. 21, from August 11, 1910, to August 30, 1911	39,263
Laguna No. 22, from July 18, 1909, to January 8, 1911	62,070
Laguna No. 23, from January 5, 1910, to January 8, 1911	11,250
Laguna No. 26, from March 30, 1910, to January 8, 1911	16,240
Laguna No. 27, from July 7, 1910, to August 30, 1911	83,400
Dicha No. 6, from February 1, 1909, to January 15, 1911	38,413
Dicha No. 8, from January 20, 1909, to August 30, 1911	92,694
Dicha No. 17, from July 30, 1910, to August 13, 1911	15,071
Chijol No. 2, from December 22, 1909 to February 3, 1910	20,400
Chijol No. 4, from December 22, 1909, to November 30, 1911	422,639
Chijol No. 5, from June 1, 1911, to November 27, 1911	130,050
Total Ebano production	10,653,822
Casiano No. 1, from March 22, 1910, to August 14, 1910	27,238
Casiano No. 2, from January 11, 1910, to August 14, 1910	29,743
Casiano No. 6, from July 26, 1910, to August 10, 1910	150,000
Casiano No. 7, from September 7, 1910, to December 15, 1912	19,000,000
Total Casiano production	19,206,981
Total Ebano production	10,653,822
Grand total	29,860,803

This table is of much interest as exhibiting the total production of individual wells, from the first one, Pez No. 1, April 3, 1904, up to the last, Chijol No. 5, completed June 1, 1911. The star wells of the two groups are, of course, Pez No. 1, at Ebano, and No. 7, at Casiano, the former still flowing 300 to 1,000 barrels daily in spite of water invasion from its near-by neighbor, No. 6, although 7½ years old, and the latter, Casiano No. 7, after having put 19,000,000 barrels into tankage in only two years and a quarter, continuing to flow at the rate of 23,000 barrels daily, accompanied by an output of 10,000,000 to 12,000,000 feet of gas, the oil being entirely free from water, while only one-half mile distant is its companion, No. 6, which was producing at the rate of 14,000 barrels and increasing daily when it was successfully closed in August 10, 1910. An attempt was also made to shut in No. 7, but the seepages around and near it began to spout oil at the rate of 2,000 to 3,000 barrels daily, and hence, for fear of another Dos Bocas blow-out, Mr. Wylie opened up the well and then gradually closed the gate valve until the pressure registered only 290 pounds to the square inch instead of 585 pounds, the rock pressure of the well and the same as that shown at No. 6, which has remained at that figure ever since it was closed in, twenty-seven months ago. Under this pressure (290 pounds) No. 7 produces oil (23,000 barrels daily) as fast as the company can take care of it by sale and storage, and for that reason Nos. 1 and 2 and 6 were shut down and drilling operations practically abandoned in other portions of the company's extensive holdings, in order that its entire resources could be devoted to taking care of the flood of oil which was pouring from No. 7, although closed in as much as possible. For this reason wells Nos. 1 and 2 at Casiano were shut down on August 14, 1910, since they were pumping wells, and have not been operated since, although No. 1 had produced an average of 188 barrels daily, and No. 2 an average of 138 barrels. Other wells in the Ebano district were also shut in when possible and not opened again for several months. One of these was La Pez No. 1, which, when shut in, was flowing an average of only 400 barrels daily, but when opened again several months later, as stated by Mr. Doheny, began flowing at the rate of 800 barrels daily, and has kept going at the higher rate ever since, apparently making up for lost time. The explanation of this curious freak on the part of Pez No. 1 is probably due to the fact that, while it was shut in, the petroleum continued to rise from below and enter the cavities and porous spaces from which it had been partially exhausted during the previous years.

Another remarkable well in the Ebano district is Laguna No. 2, which began flowing at the rate of 500 barrels daily on November 7, 1906, and in the five years and 23 days up to December 1, 1911, had put into tankage 750,240 barrels, an average daily output of 406 barrels for the entire time, and it was still flowing about 450 barrels daily in December, 1911.

The following table of production of the wells owned by the Mexican Petroleum Company, Limited, of Delaware, brings the output of the same up to April, 1913, and is supplementary to the table given for December, 1911:

Ebano, *April* 14, 1913.

Mr. **Herbert** G. **Wylie**, *General Manager.*

Dear Sir: In compliance with your instructions, I beg to hand you the following report, showing the production of Ebano wells to April 12, 1913:

	Barrels
La Pez No. 1, from April 3, 1904, to April 12, 1913	3,450.123
La Pez No. 3, from October 24, 1905, to September 5, 1911	4.342
La Pez No. 4, from July 20, 1906, to December 21, 1911	1,150,194
La Pez No. 5, from April 1, 1906, to March 28, 1912	370,951
La Pez No. 6, from January 2, 1909, to February 2, 1913	1,763,612
La Pez No. 7, from December 1, 1910, to April 12, 1913	433,988
Laguna No. 2, from November 2, 1906, to April 12, 1913	951.430
Laguna No. 3, from April 2, 1907, to April 12, 1913	1,047,132
Laguna No. 4, from April 22, 1908, to April 12, 1913	265,801

	Barrels
Laguna No. 5, from May 17, 1909, to January 8, 1911	92,810
Laguna No. 7, from June 20, 1908, to April 12, 1913	991,618
Laguna No. 10, from July 9, 1908, to April 12, 1913	178,492
Laguna No. 11, from September 17, 1908, to April 12, 1913	242,226
Laguna No. 14, from February 2, 1909, to April 12, 1913	462,706
Laguna No. 17, from May 19, 1909, to April 12, 1913	94.202
Laguna No. 19, from May 17, 1909, to January 8, 1911	90,160
Laguna No. 21, from August 11, 1910, to August 13, 1911	39,263
Laguna No. 22, from July 18, 1909, to January 8, 1911	62,070
Laguna No. 23, from January 5, 1910, to January 8, 1911	11,250
Laguna No. 26, from March 30, 1910, to January 8, 1911	16,240
Laguna No. 27, from July 7, 1910, to August 30, 1911	83,400
Dicha No. 6, from February 1, 1909, to January 15, 1911	38,413
Dicha No. 8, from January 20, 1909, to August 30, 1911	92,694
Dicha No. 17, from July 30, 1910, to August 13, 1911	15,071
Chijol No. 2, from December 22, 1909, to February 3, 1910	20,400
Chijol No. 4, from December 22, 1909, to April 12, 1913	880,229
Chijol No. 5, from June 1, 1911, to April 12, 1913	481.130
Chijol No. 6, from February 20, 1913, to April 12, 1913	2,710
Chijol No. 7, from February 9, 1913, to April 12, 1913	62,950
Total Ebano production	13,395,607

Laguna No. 10 was closed in August 30, 1911; opened August 16, 1912; closed again October 20, 1912; opened November 1, 1912; closed once more November 25, 1912, and not opened until March 25, 1913. Laguna No. 17 was closed in June 13, 1912, and opened up August 7, 1912.

In making up the above report I have taken the figures shown in the report of Dr. I. C. White of December 21, 1911, as a base, and added the gauger's reports of production from December 1, 1911, to April 12, 1913.

Yours very truly,

(Signed) J. OSWALD BOYD,
Superintendent.

The following cablegram was received from Herbert G. Wylie on April 16, 1913:

"Total production to date, Casiano well No. 7, 20,697,000 barrels."

EXTENT OF THE OIL TERRITORY

The developments in the Ebano district and Casiano by the Mexican and Huasteca companies, and at Dos Bocas, Potrero del Llano, and other points by the Mexican Eagle Company, would appear to establish on a very sound foundation the proposition first advanced by Messrs. Doheny and Canfield, namely, that wherever seepages of petroleum and natural gas come to the surface around dikes, plugs, and cones of basalt or other igneous eruptions along the Gulf coastal plain of Mexico, there we may expect to find deposits of petroleum in commercial quantity. This proposition is based on the theory that a large quantity of each must be present in order to force themselves upward to the surface from depths of 1,500 to 2,500 feet through fractures in the overlying shaly beds out of their source in the Tamasopa limestones. Messrs. Doheny and Canfield also go a step further with their generalization, and say that no productive oil territory is to be expected in regions where there are basaltic hills but no seepages. While the writer fully concurs in these views as to the interpretation of active seepages, he also believes that productive oil pools may also be found at a considerable distance from the basaltic hills for the following reasons: The existence of the seepages is due to fractures and faults made through the overlying shales by the upthrust of igneous dikes, cones, laccolites, and other types of volcanic energy which at the same time tilted the underlying sedimentaries so that their contained petroleum could segregate into pools of commercial value around the several centers of disturbance, just as the anticlinal, monoclinal, or quaquaversal disturbances of the sedimentary beds in the Appalachian and other oil fields of the United States have served the same purpose. In such a wide region as that covered by the seepages shown on the map, it would be almost impossible that no other disturbance of the sedimentaries could have taken place except in the immediate regions of volcanic activity. Of course, in such cases of anticlinal folding distant from hills or dikes of igneous rocks no important fractures of the shales overlying the oil horizons would be made, and hence no seepages of oil could appear on the surface, although large pools of it might exist in the gently folded Tamasopa limestones 2,000 feet or more below. It is true that owing to paucity of rock exposures in the dense jungles of the tropics, it may be almost impossible to find the evidence of these minor lines of folding in the sedimentaries, but, nevertheless, this is no reason that such may not exist, and therefore the writer considers it highly probable that some productive oil pools may exist far removed from the presence of either oil seepages or volcanic dikes, hills, or laccolites, since the same great petroliferous limestones (Tamasopa) underlie the entire Gulf coast region and only require to be tilted at a small angle in order to make possible the accumulation of commercial pools of oil along such axes of disturbance or folding.

THE QUESTION OF SALT WATER

Ever since the Dos Bocas gusher ran wild and began to belch up such enormous volumes of hot salt water that the estimates thereof run into millions of barrels daily, many oil experts have reasoned that a like fate of "going to hot salt water suddenly" awaits every other gusher oil well that exists or may hereafter be developed in the Mexican fields. This conclusion, however, does not appear to rest upon sufficient evidence to justify such an important generalization. In the first place, it is the evidence of only a single well, which many of the most practical oil experts regarded as a "freak," entirely out of the regular conditions to be found in most of the Mexican oil pools. Mr. H. G. Wylie and Doctor Paddleford, who saw the well soon after it took fire and while all the oil it was producing was being consumed high up the air so completely that not a drop returned to the earth, say that the Dos Bocas well was a great gas well, rather than a great oil well, and that in their opinion the well never put out more than 15,000 to 20,000 barrels of oil daily before access of water ended its spectacular career, both as an oil well and as a gas well. The opinions of such well qualified experts as those of the general manager and general superintendent of all the properties of the Mexican Petroleum Company, Limited, are certainly entitled to great weight. Then, too, the situation of the Dos Bocas well, not far from the shore of a vast body of water—Lake Tamiahua—where fissures, faults, and dikes give abundant opportunity for surface waters to descend into the earth in great volume, as attested by the continued enormous flow of hot (160° Fahrenheit, according to Dr. C. W. Hayes, general manager of the Pierson interests, and even above 212°, according to other testimony) salt water continually ascending from the crater-like mouth of the well in question, along with much gas and petroleum cooked into balls of asphaltum, is the most favorable location possible for such an unique exhibition as Dos Bocas has given. The conditions surrounding it and the gushers at Casiano are entirely different, since Casiano is several miles removed from any large body of water, and as No. 7 well there has already put into tankage 19,000,000 barrels of oil without any signs of water or diminution in either original rock pressure (585 pounds), or flow of both oil and gas, there does not appear to be any valid reason for the apprehension expressed by some that the Casiano pool may "go to hot water suddenly, just like Dos Bocas"; in fact, the methods of sinking and protecting the wells against invasion of water from above or laterally through fissures and fractures of the inclosing walls of the borings would seem to give assured security against such disastrous results. This method of drilling consists of forcing cement down the outside of each string of casing immediately after it is set and continuing the filling until the fractures will take up no more, thus giving a solid wall of reinforced concrete from the top to the bottom of the last string of casing, which is to be set in the solid cap rock of the Tamasopa limestone. Then, just before entering the "pay," generally found at about 30 feet under the top of the capping limestone, the hole is to be filled with cement up above the bottom of the last string of casing and left undisturbed for several days, until it hardens and completely closes any remaining fissures that might possibly give trouble, before the drill is finally sent through the cement and the few remaining feet of limestone above the oil horizon. This method, devised by General Manager Wylie after several years of experience with conditions in the Ebano district, which simulate in a miniature way those surrounding the Dos Bocas well (since a surface Laguna also exists during the rainy season between Ebano Hill and La Pez), will, of course, add materially to the cost of drilling; but the added cost will be much more than offset in the freedom from danger of losing a large well when it becomes necessary to shut it in for want of storage, as was imminent with Casiano No. 7 until the good judgment of Mr. Wylie intervened and permitted it to flow under only half its normal (585 pounds) pressure, and thus stopped the numerous streams of oil which had begun to issue from every fissure over a considerable area around the well while it remained closed.

The history of wells Nos. 1 and 6 La Pez, in the Ebano field, throw interesting side-lights upon the water question in the region of lakes or lagunas. After La Pez No. 1 had been flowing steadily for nearly five years, La Pez No. 6, only a few hundred feet distant from No. 1, came in, January 3, 1909, flowing at the rate of 8,000 barrels daily, 40 per cent of which was water. Almost immediately water began to appear in La Pez No. 1, although it was producing from a level 300 feet above the bottom of No. 6, the water from the latter evidently having found its way across to No. 1 through fractures and fissures extending between the two holes. It was Mr. Wylie's experience with these two wells which suggested to his practical mind the policy of preventing any such recurrence by closing up with cement all such avenues of communication of one well with another.

This La Pez No. 6 is also a good illustration of the fact that a well may produce a large quantity of salt water and yet continue productive for a long time, since it had put into tankage 1,323,837 barrels of oil up to December 1, 1911, and is still flowing at the rate of 700 to 800 barrels daily, in spite of the large quantity of water which comes with the oil; while La Pez No. 1, although producing 10 to 15 per cent of water, apparently as an overflow from No. 6, still flows at the rate of 800 barrels daily, after having put into the tanks 3,178,983 barrels of oil up to December 1, 1911. This experience with salt water in the Ebano field has a very important bearing on the factors which enter into the estimates of oil production in other fields, since the fact is here very forcibly illustrated that the Dos Bocas instance of a large well "going to water suddenly" can not be regarded as an example of what will happen to all other large wells.

The Potrero del Llano well, which has already put out several million barrels of oil and would probably flow 40,000 to 50,000 barrels daily if fully opened up, is still producing perfectly dry oil under its original rock pressure, which is 850 pounds to the square inch, according to Doctor

Hayes, although two other wells only 1,000 feet distant have rock pressures of only 580 pounds, or the same as the Casiano wells. Hence, until a well like this one or Casiano No. 7 does actually "go to hot water suddenly," the danger from that source must be regarded as entirely theoretical and remote rather than practical and imminent.

Casiano well No. 7 is undoubtedly the greatest oil producer of the world, so far as total output is concerned. The Potrero del Llano well of the Mexican Eagle Company has the greater daily capacity (100,000 barrels), but as it has been shut in much of the time since it was controlled, early in 1910, its commercial production is not yet probably half that of Casiano well No. 7, which was about 19,000,000 barrels up to December 1, 1912, and still continuing its great production of 23,000 barrels daily with marvelous regularity, having no water whatever and only two-tenths of 1 per cent of sediment.

From this review of the Mexican Gulf coast fields it can readily be seen that it is one of the greatest oil regions yet developed and that it gives promise of supplying much fuel in competition with coal to all of our Atlantic coast cities. The cost of the oil to the Mexican Petroleum Company, delivered on board tank steamers at Tampico, is slightly less than 14 cents per barrel of 42 gallons, and the cost of transportation from there as far north as Boston is only about 20 cents per barrel.

OTHER UNDEVELOPED OIL LOCALITIES

Besides the regions where petroleum has already been developed, by drilling in the localities of large seepages like Ebano, Casiano, Potrero del Llano, and others, the following additional localities at which prominent seepages occur were noted by the writer:

Cerro Azul.
Juan Felipe.
Moralillo.
Chapopote Nunez.
Los Higueros.
Cerro Viejo.
Cerro de los Barrachos.
Cuchillo del Pulque.
San Geronimo.
Monte Alto.
San Miguel des Tres Aguas.
La Merced.
Chinampa.
Cervantes.
Monte Gordo.
Chapopotillo.
Tres Hermanos.
Chichihual.
Cerro de Tiapajua.
Leinon.
Palo Blanco.
Rancho Abajo.
Zacamixtle.
Monte Grande.
La Laja de Monte.
Ojo de Brea.
Callejon.
Rio Clara.
San Francisco.
Los Mosquitos.

Two of these are of special interest, namely, Cerro Viejo and Moralillo. At the former a well was sunk 25 to 30 years ago and large quantities of oil were found, since the casing is still in the well, and when the gate valve is opened the oil, a heavy black fluid, pours out in a steady stream. The locality, however, is in the midst of a tropic jungle remote from any means of transportation, and its former owner (reported to have been a resident of Massachusetts) does not appear to have realized that the oil had any value, although the tract on which this well was drilled extends along the western bank of the Buena Vista River, only 100 feet distant from the great Potrero del Llano well.

The seepages at Moralillo are interesting, since at one of them the oil is oozing from the joints of the basalt, proving not that the oil had an igneous origin, as President Fairchild and Mr. Eugene Coste would probably insist, but that the path of least resistance to the surface from its origin in the sedimentary beds below was in this case not through the close-grained shales immediately above, but along the fracture made by the basalt, and out to the surface through the more or less open joints of the same. That the conditions for accumulation of oil and gas in commercial quantity are due primarily to the upward bulging of the strata produced by the outflow of the basalt through the sedimentaries, whether in the shape of cones and dikes which reach the surface, or laccolites below the same, all agree who have studied the matter. Of the several ideas already published on the subject and illustrated, the first was by Frederick G. Clapp, Fellow of this Society, in Economic Geology, Volume VII, No. 4, for June, 1912, pages 364 to 381, inclusive.

The other illustrations represent the ideas of V. R. Garfias, of Los Angeles, who, from the experiment of driving a nail through an unbound book with thicknesses comparable to that of the intrusions of basalt and the adjoining sedimentaries, secured rents and distortions in the leaves of the paper similar to that shown in these diagrams, as illustrated in his article on this subject published in the Journal of Geology for October-November, 1912, Volume XX, No. 7, pages 666 to 672, inclusive. It is quite probable that the views of both Clapp and Garfias are correct and that all these types of disturbance may exist in the regions where the seepages occur. The great well, Casiano No. 7, is drilled so close to the hill of diabase, which crops within 400 to 500 feet of the well, that if the plug of basalt were conical the boring would undoubtedly have penetrated the same before it reached a depth of 2,112 feet, where the oil was found in the top of the Tamasopa limestone.

Chijol well No. 5 of the Ebano group, where a dike of basalt 21 feet thick was struck at 116 feet, would also appear to favor the occurrence of structures like those suggested by Garfias.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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NOTE ON A VERY DEEP WELL NEAR McDONALD, PENNSYLVANIA[1]

BY I. C. WHITE

(Read before the Society December 30, 1912)

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LOCATION AND DEPTH OF WELL

To Pennsylvania belongs the honor of the deepest boring in America. A well on the land of R. A. Geary, about 5 miles northwest from the town of McDonald, near the line between Allegheny and Washington counties, has now attained a depth of 6,052 feet.[2] This hole is being drilled by "The People's Natural Gas Company," a former subsidiary of the Standard Oil Company, of which Mr. John G. Pew, of Pittsburgh, is president and L. F. Barger general superintendent, and it is through their courtesy and that of Mr. J. B. Corrin, assistant superintendent of the Hope Natural Gas Company, that the writer was given access to the geologic data developed by the boring. Mr. Pew has chosen for the location of this deep well test the summit of the Condor dome, a structural feature in the rocks described in the Burgettstown-Carnegie Folio by E. W. Shaw and M. J. Munn, of the United States Geological Survey. On this dome the Pittsburgh coal attains an elevation of 1,180 feet above tide, the well mouth being at 1,050 feet, or 130 feet lower, thus beginning at exactly the same geologic horizon as the deep well (5,575 feet) drilled on the farm of William Bedell, 20 miles southeast of the Geary well, near West Elizabeth, Allegheny County, Pennsylvania, by the late W. J. Young, of the Forest Oil Company, the detailed log of which is published in volume I (A) of the West Virginia Geological Survey, pages 103-107, and which remained the deepest boring in the United States up to the latter part of 1912, when it was surpassed by the one herein described and by another in West Virginia, which has now attained a slightly greater (5,595 feet) depth.

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[1] Manuscript received by the Secretary of the Society December 31, 1912.
[2] The well, on May 27, 1913, had reached a total depth of 6,299 feet.

PURPOSE OF THE WELL

The Condor dome of the Burgettstown quadrangle has already produced a large quantity of natural gas from the Pottsville, Big Injun, "Hundred-foot," and Thirty-foot Sands, and Mr. Pew and his field superintendent, Mr. Barger, concluded that this region, from which the strata dip in every direction, would be a good location to make a test for any oil or gas bearing sands that might be found lower in the geologic column, hoping finally to reach the *Clinton* and even the *Trenton Limestone,* the two great gas-bearing and petroliferous horizons of Ohio. The writer figures that the Clinton horizon should be struck in this well at about 7,000 feet and the Trenton at approximately 8,000 feet.

METHOD OF CONSTRUCTION

A steel cable is in use, the derrick has double strength, and a larger engine and more boiler capacity have been provided than in drilling wells to the usual depths, so that Mr. Pew confidently expects to make the Geary well the deepest one in the world. Some trouble has been experienced by the caving of the walls in the soft shales above the Corniferous limestone, but when the temporary fishing job now on hand (a set of tools having been caught by the caving shales) is completed, the bore-hole will be lined with steel casing, so as to prevent any further trouble from caving.

RESULTS OF TEMPERATURE DETERMINATIONS

As is well known, Prof. William Hallock, of Columbia University, made careful temperature tests on the West Elizabeth or Bedell well down to a depth of 5,000 feet, where the temperature was 120.9° Fahrenheit, and he also tested the Wheeling, West Virginia, deep well, finding a temperature of 110.3° Fahrenheit at 4,500 feet, and the two wells agreed very closely in temperatures throughout at the same depths. Figured on the basis of increase from 4,500 feet to 5,000 feet in the Bedell well, a temperature of about 144° Fahrenheit should be found in the Geary well at 6,052 feet, its present depth, and this estimate is probably very nearly correct, since Mr. Pew reports that a temperature of 140° Fahrenheit was recorded at 5,800 feet in the Geary well, which is about what the West Elizabeth and Wheeling results would indicate for that depth.

RECORD OF THE WELL

The following is the record of the R. A. Geary well, or No. 1770 of the People's Natural Gas Company, to its present depth. It is located 5 miles northwest from McDonald, Pennsylvania, at the head of Little Raccoon Creek, near the line between Washington and Allegheny counties. The well mouth is about 1,050 feet above tide and begins 130 feet below the horizon of the Pittsburgh coal bed.

	Thickness feet	Total feet
Conductor	..	16
13-inch casing	..	232
Unrecorded to	..	450
Limestone	20	470
Slate	125	595
Kittanning coal; water at 600 feet	5	600
Unrecorded	134	734
Salt sand; gas at 760 feet and 912 feet	216	950
Pencil cave	3	953
Big lime	29	982
10-inch casing	..	953
Big Injun sand; gas at 1,052 feet	259	1,241
Unrecorded	137	1,378
Squaw sand; gas at 1,379 feet	14	1,392
Unrecorded	218	1,610
Sand (Berea)	12	1,622
Unrecorded	172	1,794
Hundred-foot sand; gas at 1,797 feet	23	1,817
Unrecorded	93	1,910
Thirty-foot sand; gas at 1,912 feet	15	1,925
Unrecorded	43	1,968
Gordon stray sand	3	1,971
8¼-inch casing	..	1,969
White slate	1,019	2,990
Limestone	220	3,210
White slate	230	3,440
Limestone	10	3,450
White slate	650	4,100
Sand and lime	70	4,170
White slate	350	4,520
Black slate	30	4,550

	Thickness feet	Total feet
White slate	650	5,200
Black slate	120	5,320
Black shale	200	5,520
White slate	140	5,660
Limestone (*Selinsgrove*)	20	5,680
Black lime (*Selinsgrove*)	108	5,788
Black slate (*Marcellus*)	220	6,008
Black lime (*Corniferous*)	15	6,023
Flint (*Corniferous*)	22	6,045
Sand, grayish white (*Oriskany*)	7	6,052

The identifications in parentheses are the writer's.

DISCUSSION OF THE SECTION

The interval in the Geary well from the base of the Berea Grit (1,622 feet) to the top of the Corniferous limestone (6,008 feet) is 4,386 feet, while on the south shore of Lake Erie, near Elyria, Ohio, 115 miles to the northwest, this same interval is only 800 feet. These intervening Devonian shales, however, increase rapidly in thickness southeastward, since at Akron, Ohio, only 35 miles from Elyria, they have a thickness of 1,862 feet, an increase of 30 feet to the mile; while from Akron to the Geary well, a distance of 80 miles, this thickening (1,862 feet to 4,386 feet), 2,524 feet, continues at only the slightly greater rate of 31½ feet to the mile. This southeastward thickening of 31½ feet to the mile from the region of Akron will furnish a convenient measuring rod for estimating the depth at which the Corniferous limestone may be found, and consequently the Clinton and Trenton petroliferous rocks below, over the present oil and gas fields of western Pennsylvania and West Virginia. According to the elder Orton, the top of the Corniferous limestone falls from 225 feet below tide at Elyria to 925 feet below at Akron, or at the rate of 20 feet to the mile, while from Akron to the McDonald region the descent is at the rate of 40.3 feet per mile, or double the rate to Akron, since the top of the Corniferous lies at 4,950 feet below tide in the Geary well. This rapid dip of the lower formations should lead to the accumulation of some oil and gas pools in the porous zones of the Clinton and Trenton petroliferous horizons along the interrupted or terrace structural belts of these horizons between Akron and McDonald; and since the Geary well is located on a well-marked dome in the surface rocks which has proven very prolific in all of the higher porous sand reservoirs, gas will most probably be found with very high rock pressures in the Clinton and Trenton horizons at this location, should the rocks in question have sufficient porosity to afford good reservoir capacity.

It is interesting to note here the presence of a limestone (Selinsgrove) horizon as a portion of the Marcellus shale group, first described by the writer in Report G7 of the Second Geological Survey of Pennsylvania, from the region of Selinsgrove, on the Susquehanna River, in Northumberland County, as also the Corniferous limestone, with its included flint nuggets, and the underlying Oriskany sandstone in which the well was drilling when the tools were temporarily lost.

THE GAS AND ITS CONTROL

While passing through the black slates and shales of the Hamilton series above the Corniferous limestone several successive pockets of gas were encountered. These had such an enormous initial pressure that the escaping gas would blow the heavy tools several feet up in the hole, occasionally giving trouble from breaking of the wire cable, when they would drop back after the sudden flow of gas had passed, and whose approach to the surface could be heard in advance with an intense roaring noise.

It will prove an interesting problem to confine and control any commercial deposits of natural gas that may be found in the Clinton horizon of this well at an approximate depth of 7,000 feet, since if the rock pressure increases in the same proportion as is customary with depth, namely, about 45 pounds to the square inch for every 100 feet of depth, the gas pressure in the Clinton horizon should approximate 3,000 pounds, a figure with which the oil and gas engineers have had but little experience, since no natural gas pressures have yet been recorded, in the Appalachian field at least, which exceeded 1,500 pounds. As one means of dealing with an immense pressure, and one which appears entirely feasible, Mr. Barger, of The People's Natural Gas Company, plans to let the gas feed into the porous sands whose gas has been largely drained from the upper portion of the boring, thus refilling these exhausted reservoirs and finally restoring their original rock pressures, or even exceeding them, from which the gas can be led into the field lines under the customary rock pressures of these upper sands. In this event these higher sands would act in the same manner as a reducing or regulating valve does in stepping down high pressures to lower ones along the present transmission lines before the gas reaches the point of consumption.

FACILITIES OFFERED FOR SCIENTIFIC RESEARCH

Mr. Johnson, of the United States Bureau of Standards, will have charge of and be given every facility for securing accurate temperature measurements of this deep well, and as the locality is in the undisturbed region where Dr. William Hallock has done such excellent pioneer work along this line, very interesting and valuable results may be expected, especially if the boring shall attain a depth of 8,000 feet or more, which Mr. Pew says it will, if money, machinery, and expert drillers can succeed in making a hole in the earth to that great depth. Too much praise cannot be given Messrs. Pew, Corrin, Barger, and others connected with The People's Natural Gas Company for the public spirit they have shown in dedicating this expensive well to the interests of pure science.

POSTSCRIPT

Under date of May 27, 1913, Mr. L. F. Barger, general superintendent of the People's Natural Gas Company, has furnished additional data concerning this most interesting well. The drill had attained a depth of 6,052 feet on December 31, 1912, when this paper was read at New Haven, and a set of drilling tools was then in the hole, caught by the caving shales above. The tools were finally recovered, and to prevent any recurrence of such troubles the 6⅝-inch casing was inserted at 6,053 feet, 8 feet in a brownish gray sand, which the writer tentatively identifies with the *Oriskany*. The record from the bottom of the *Corniferous flint* at 6,045 feet down to the present depth on May 27, 1913, is given as follows by Mr. Barger:

	Thickness Feet	Total feet
Sand (water and gas, 6,060 feet)	155	6,200
Brown sand	60	6,260
White sand (salt water, 6,260 to 6,265 feet)	10	6,270
Brown sand to bottom	29	6,299

Explosive gas flow at 4,850 feet.
Explosive gas flow at 4,870 feet.
Explosive gas flow at 5,900 feet.
Explosive gas flow at 5,905 feet.
Explosive gas flow at 5,910 feet.
Explosive gas flow at 5,915 feet.
Explosive gas flow at 6,060 feet.

Temperature measurements taken in well:

	Temperature, Fahr.
At 5,150 feet	110°
At 5,220 feet	120°
At 5,800 feet	140°
At 6,000 feet	100°*
At 6,095 feet	156°
Taken in water 6,270 feet	156°

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* Evidently reduced by natural gas expansion.

The water found at 6,260 feet rises in the hole to a height of 4,000 feet, or to 2,299 feet below the top of the well. Its chemical composition is as follows, according to an analysis of a sample made by the Pittsburgh Testing Laboratory—H. H. Graver, chief chemist:

Specific gravity at 60° Fahrenheit	1.1085
Oil	Trace
	Parts per 100,000
Alkalinity as calcium carbonate	5.50
Calcium chloride	4,421.40
Magnesium chloride	251.60
Sodium chloride	5,018.20
Sulphuric anhydride	Trace
Iron oxide	Trace
Sediment (rock powder)	224.60
Total solids	9,921.30
Total solids exclusive of pulverized rock sediment	9,696.70

This analysis looks as though we had here a case of fossil ocean water imprisoned since mid-Paleozoic time. An effort is being made to exhaust it by pumping, so that the well can be drilled to much greater depths in search of the Clinton or Medina petroliferous beds, and possibly to the Trenton horizon, 1,000 feet lower.

The immense quantity (239 feet) of *sandstone* at the horizon of the *Oriskany,* which continues below the present depth, was unexpected at this locality, but is duplicated at the Lehigh River, in Carbon County, Pennsylvania, as described in the writer's Report on Pike and Monroe counties, G6, of the Second Geological Survey of Pennsylvania, page 124, where the Stormville shales and sandstones at the top of the Lower Helderberg series appear to have coalesced with the Oriskany beds, thus forming one great mass of sandstone over 200 feet in thickness. Hence it is possible that this 239 feet of sandstone may represent a portion of the Lower Helderberg rocks, since a regular sandstone bed, the Deckers Ferry sandstone of Monroe County, Pennsylvania,[3] sometimes occurs well down toward the base of this group of rocks.

Mr. Pew and Mr. Barger will make every effort that financial resources and drilling talent can supply to sink this well to a depth of 8,000 feet, thus making it the deepest well in the world and rendering available a knowledge of the thickness and character of the underlying Paleozoic beds at this interesting locality, so far removed from any exposure of these rocks, the nearest Oriskany outcrops being at Altoona, Pennsylvania, and Keyser, West Virginia, each of which is nearly 100 miles distant and in the heart of the Alleghany Mountains.

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[3] Report G6, Pike and Monroe counties, Second Geological Survey of Pennsylvania, page 140.

The great reduction in temperatures found at 6,000 feet is due to the sudden expansion of natural gas, a small flow of which under great pressure (probably 2,500 pounds or more to the square inch) was encountered near and below that horizon. The temperature of 156° Fahrenheit, recorded first at 6,095 feet, is, however, so much greater (156° to 140°), namely, 16°, than that (140°) recorded at 5,800 feet that it probably was elevated a few degrees by the pounding of the drill on the hard sandstone, and this looks all the more probable, since the water found at 6,250 feet has only the same temperature (156°), which itself reveals a rapid increase in gradient below 5,800 feet, or at the rate of 1 degree for every 29 feet. The results of other temperature measurements on this well at greater depths will prove of surpassing interest.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

CERTAIN THEORETICAL CONSIDERATIONS AFFECTING PHYLOGENY AND CORRELATION[1]

BY W. D. MATTHEW

(*Read before the Paleontological Society December 30, 1912*)

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THEORY OF CENTERS OF DISPERSAL

In a former communication to the Society[2] I discussed the evidence for the continuity of evolution from the standpoint of vertebrate paleontology. The theory adopted to interpret the evidence was that of evolution of each race in a center of dispersal, and spread from there in successive waves of migration to other regions. The present contribution aims to discuss certain phases of this theory in their effect on the structure and affinities of a phyletic series in a region remote from the center of dispersal.

The considerations to be presented and their effects on the composition and affinities of a race are familiar to modern ethnologists. They are recognized facts of the dispersal of the human races, and their effect on the affinities of each race is clearly seen and universally recognized.

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[1] Manuscript received by the Secretary of the Paleontological Society January 28, 1913.

[2] Continuity of development. Popular Science Monthly, Nov., 1910.

Their application to zoological, and especially to paleontological, studies is, I believe, no less exact, but has received little attention.

Admixture of Blood through Migrations

In presenting the theory of dispersal in its application to fossil vertebrates, it is convenient to speak of a series of waves of migration proceeding outward from a center of dispersal. In fact this is a somewhat misleading phrase. What must really have occurred is rather a more or less continuous stream of new blood pouring into the region considered, mixing with the older blood and gradually displacing it. If the course of migration be uninterrupted and the environmental pressure be more or less continuous in its action and direction, the progress of a race in a given region will be due partly to the infusion of new blood from the adjoining region nearer the center of dispersal, partly to the adaptive influence of the local environment, partly to the substitution of new species or genera arriving from regions nearer the center of dispersal and which either were originally or have become infertile with the autochthonous species.

In discussion of the evolution of a phylum, the second and fourth of these influences have usually been considered. But it would seem that all four have frequently, if not generally, played an important part in determining the evolutionary progress of a phylum in any locality. The representatives of a phylum at any one stage in its development in a given region do not consist of one or several homogeneous species or pure races, but of series ranging from archaic autochthones to recent immigrants, more or less broken into nodes or separated groups by local segregation or the partial extinction of intermediate members of the series.

The English Race as an Illustration

Let us consider, first, what we know to have been occurring in the migrations of the human race and its effect on the population of Great Britain. When this island first appears in history its population is somewhat heterogeneous. The inhabitants of the south and east are closely allied to the Gauls. Northward are traces of Scandinavian and in Ireland of Iberian affinities. The Roman occupation, while it checks migration for a time, does not introduce any important new ethnic element, but toward its close the normal course of migration is resumed and an ever increasing flood of Platt-Deutsch peoples pours in. The effect of the hindrance of migratory movements during Roman times is seen in a partial disinclination to free admixture, and a certain degree of segregation between the Teutonic invaders and Celtic aborigines is evident, and indeed persists to some extent today. Following the Saxons and Angles came Jutes and subsequently Danes, forming the dominant element of the eastern coast, while the Norman-French spread a new layer of population over the whole country. Subsequently the south and east receive new increments of population from the Netherlands and later from France. There is likewise a considerable movement of population from Scotland south into England and the north of Ireland, from England into Ireland, and more recently from Ireland back into England. Setting aside the concentration into the cities and considering only the rural population, these, with other minor movements, afford the necessary data for interpretation of the wide variations in physical type in different parts of the British Isles. The unity of type among Englishmen is based on language, customs, and conventions, in some degree perhaps on natural environment; but it covers a wide diversity of blood. The Englishman is not merely of mixed race, but the admixture varies greatly locally. This is almost equally true of every civilized race, and it is to a very large extent true of every uncivilized race.[3]

The evolution of the human race in any one region has been chiefly through successive infusions of new blood, not through the replacement of one race by another; and this is true of barbaric races. The dominant race absorbs the remnants of the older blood or is absorbed by autochthones, but the continued renewal of new invading elements disturbs the homogeneity of the population before it is complete, and enables a very archaic strain to be preserved to some extent in association with new elements, which would not have fused with the ancient blood except through the intermediary of successive previous invasions of intermediate stocks.

Applicability of the Principle to Animals

The evolution of mammalian races must have proceeded, so far as I can see, on much the same lines. If so, when we come to make detailed studies of the evolution of mammalian phyla, these controlling circumstances must be carefully kept in mind. If these principles be true, then in the normal course of evolution of a race in a given region, each stage will consist of a complex of groups of varying blood-mixture, inextricably tangled up, each individual being a product of indirect hybridism of many ancestral strains, some of which would be generally regarded as distinct species.

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[3] The heterogeneous and complex composition of all human races is strongly emphasized in Boaz's recent book, "The Mind of Primitive Man." Dr. Boaz compares it with the composite character of domesticated species of animals, and contrasts it with the supposed purity of wild races. But I do not think that there is any such contrast. Wild animals, like domestic, are of mixed and composite blood, but their admixture has gone on under natural law and conditions, producing certain limitations and uniformities of the resultant that distinguish it from the artificial admixtures present in domesticated races.

The old Linnæan species concept was founded on supposed impossibility of blood relationship between mutually infertile forms; the current concept makes the specific group dependent rather on local or preferential segregation than on infertility for their distinctness. But if the migration and dispersal of a race involves this sort of indirect hybridism, even the broader concept of the Linnæan species will not secure complete racial distinctness to the subphyla of a polyphyletic group. The horse and the ass are today immiscible, yet the wild horses, if we assume that they are a later invasion, occupying territory formerly peopled by asses, probably have ass blood in their veins, and individuals should present varying proportions of characters due to that inheritance. It is not indeed the characters of the modern ass that should appear, but the characters of (1) the ass stage in the center of dispersal of the Equidæ, more remote and more modified by evolutionary change, but reinforced by (2) admixture of the remnants of the former equine population of the region invaded by the true horses.

The net results of this process of admixture will be to produce a reactionary effect on the characteristics of an invading group as it reaches regions remote from its center of dispersal, through continual and progressive absorption of its predecessors in the dispersal of the race. This will be added to the effect of the local environment and of earlier environments which it has passed through; and all these factors dependent on shifting habitat must be added to those which operate in a fixed habitat to produce or control evolutionary progress in a race of animals evolving and spreading out from a center of dispersal.

Whether the characteristics be inherited according to Mendelian laws, or be fluctuating variations tending to revert to type, will not affect the results of this continuous admixture and readmixture, so far as I can see. Nor will it make any particular practical difference from the present point of view whether Mendelian characters arise suddenly or gradually. Under the stated circumstances, it will not be possible to eliminate a Mendelian character any more easily than a non-Mendelian character. The problem is far too complex and the data are too scanty to afford conclusive evidence as to such niceties. We can obtain and be sure of approximate results and these only. Thus the three strains which Ewart has shown to exist in the domestic horse present a convenient approximate statement of the facts; but the exact sources are probably vastly more complex, the original strains are themselves composites of complex origin, and the present habitat of the nearest living representatives of these strains is not their original home.

Effect of interrupted Migrations

The problem has thus far been treated on the assumption of free opportunity for dispersal and continuous environmental pressure, producing a continuous stream of migration. But in fact we must expect periodic interruption of greater or less duration in this movement, due either to barriers interposed or to temporary cessation or reversal of the environmental pressure, of whatever nature this may be. These interruptions, if short, will produce nodes; if longer, actual breaks in the stream as it moves forward in time and space. The nodes in the further progress of the stream will tend to disappear; the actual breaks involving infertility may, if sufficiently great, be permanent. In a region far from the center of dispersal the arriving stream will preserve completely or partially all the nodes and breaks due to interruptions at former stages of its progress, the nodes tending to disappearance, the well marked breaks to sharper accentuation. Hence the farther away we are from the center of dispersal the more the race will be broken up into sharply differentiated species or genera, and the less in proportion will there be of nodes or imperfectly differentiated and anastomosing groups.

Effect of Remoteness from Dispersal Center

Furthermore, a race remote from its center of dispersal will have passed through many different local environments on its way, and each of these, especially during interruptions of the migration movement, will have tended to impress on its members a local adaptive radiation, which will increase and intensify the diversity of the resultant in its further course. The influence of the typical evolution of the race proceeding in its center of dispersal will be more remote; that of the various divergent adaptations passed through will be more dominant, as the race is more remote from its original home.

Near the center of dispersal, therefore, we should expect to find the specific and generic groups of a family difficult to distinguish, intergrading a great deal and held more strictly to type. Far from the center of dispersal we should expect more sharply differentiated species or genera, more diversity of type, and more aberrant forms.

TRUE NATURE OF A PHYLETIC SERIES

In view of the above considerations, what is the real nature of a phyletic series, such as may be found in the successive geologic strata of any region? Evidently its successive stages are not wholly in genetic sequence unless we are in the exact center of dispersal of the group. Nor are they wholly successive immigrants arriving unaltered from that center. Each stage is a complex and non-homogeneous group derived from earlier and later strains of immigrants, modified to varying degrees by the various environments through which they have passed. To disentangle such a complex in any accurate and exact way is humanly impossible, even where our material is abundant. Their approximate relations may be presented in the form of a polyphyletic succession, but all such subphyla must needs be more or less arbitrary and inexact. It is only in the larger phyla that the arrangement accords with the real genetic sequence.

CORRELATION OF HOMOTAXIAL STAGES OF A PHYLUM

There is one phase of this discussion that bears on the question of correlation. It is customary to regard the appearance of equivalent stages in a phylum in the formations of widely separated regions as the most conclusive evidence of synchronism. This may be true where the regions are equidistant from the center of dispersal of the group in question. Where they are not, two considerations affect the conclusion. First, there is the distance in time of migration of the race from the dispersal center to the two regions compared, and this may be considerable, even in a geologic sense. Second, there is the reactionary influence of previous stages in the evolution of the group absorbed into the advancing new stage on its way. This latter is more considerable in its influence than might at first be supposed on species remote from their place of origin of the group. By assuming certain special cases, it is possible to calculate what effect it has.

In the accompanying diagram the horizontal distance left to right represents geographic migration from the center of dispersal. The vertical distance from below upward represents geologic time-relations. A, B, C, D, E, F represent successive geographic varieties or species, formed by the influence of the local environments when the dispersal of the race begins. 1, 2, 3, 4, 5, 6, etcetera, represent successive geological mutations or phyletic stages in the center of dispersal. The upward trend of the line A–F covers the time required for a migrating stage to reach the region F from the center of dispersal. The line of direct genetic sequence at the center of dispersal will be represented by A, A^1, A^2, A^3, etcetera.

According to the theories set forth above, we will have at region B first the descendants of A, becoming modified by the B environment; at region C the descendants of A, partly modified by B and C environments, and so on. The next mutation in region B will consist of the incoming migrants of the A^1 stage, mixing with and partially displacing the original B, derived from A. Assuming as a special case that the newcomers displace three-fourths of the earlier stage and absorb the remaining fourth, then the B^1 mutants will contain (as an average) 3/4 of A^1 blood, 1/4 of A blood already somewhat modified by B environment, or $B^1 = 3/4\ A^1,\ 1/4\ A$.

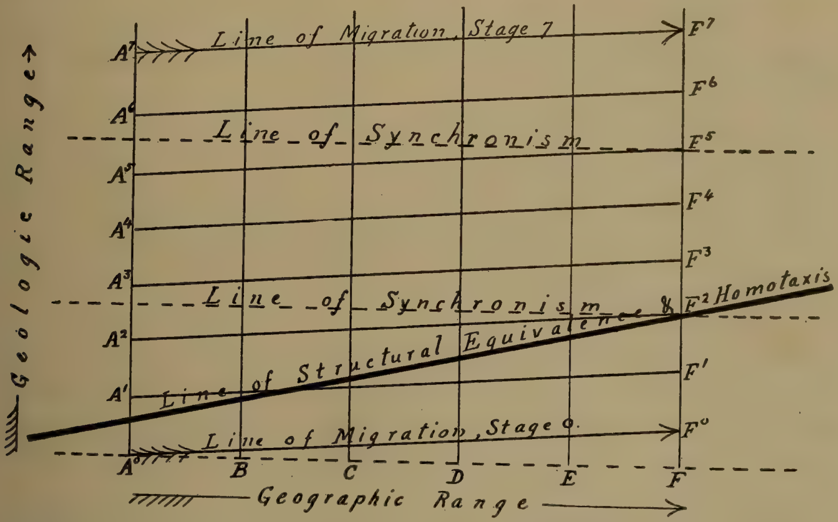
Line of Migration, Stage 7
F⁷
A⁷
F⁶
A⁶
Line of Synchronism
F⁵
A⁵
F⁴
A⁴
F³
A³
Line of Synchronism & Homotaxis
F²
A²
Line of Structural Equivalence
F'
A'
Line of Migration, Stage 0
F⁰
A
B
C
D
E
F
Geographic Range
Geologic Range

FIGURE 1.—*Relations of homotaxial and synchronous Stages in a widely dispersed Phylum*

Carrying on the same special case, we will have

$$C^1 = 9/16\ A^1 + 3/16\ A + 1/4\ AB.$$

The modifying influence of the B environment is really somewhat greater than this.

At F^1 the approximate figures will show

1/4 A^1 influence (23.73 per cent).
1/6 A blood.

The remainder is A blood modified by the environments B, C, D, and E.

In other words, the successive remnants of the earlier stage absorbed by mutation 1 on its journey from A to F have brought it nearly back to the earlier phyletic stage, although the new stage displaced most of the individuals of the earlier stage in each region it traversed.

If now we calculate the affinities of the next phyletic stage in its progress from A^2 to F^2, we will find that

$$B^2 = 3/4\ A^2 + 3/16\ A^1 + 1/16\ A,$$

and when we arrive at F^2 we find that the approximate percentages are

A^2 = 24 per cent.
A^1 = 29 per cent.
A = 13 per cent.
AB = 12 per cent.
ABC = 10 per cent. A and modifications, 49 per cent.
ABCD = 8 per cent.
ABCDE = 6 per cent.

In terms of structure this means that the representatives of the third phyletic stage by the time they reach region F will have reverted so far as to be less advanced than the second stage, and also undergone a large amount (36 per cent) of atypical modification from the intermediate environments.

If we were correlating the fauna of region A with the fauna of region F on the usually accepted basis of identical or equivalent species, we should conclude that the appearance of F^2, which is between A and A^1 in its structural progressiveness, should be correlated with strata in region A between A and A^1. In point of fact it is later than A^2 by the amount of time required for a migrating stage to traverse the distance A to F.

Correlation of Cenozoic Mammal Faunæ

These considerations have some bearing on the correlation of Tertiary horizons in Europe and the United States; but so much of our mammalian fauna is derived from dispersal centers more or less equidistant from these two regions that no serious error can ensue from neglecting them. The case is somewhat different when we correlate the faunæ of the southern continents with those of the Holarctic realm. In these we should evidently make some allowance for the time required to reach regions remote from the dispersal center and for the reactionary effect of absorption of more primitive stages. Both will tend to make southern representatives of northern groups seem more ancient than they really are. Conversely, northern representatives of southern groups will be more primitive than their contemporaries in the south, and in certain correlations the comparison of the two may furnish the mean homotaxial relation representing actual synchronism.

The Pampean Fauna: Equidæ and Ground Sloths

Equus, for instance, appears first in the Upper Pliocene in the Old World, Lower Pleistocene in North America, Middle Pampean in Argentina. It is of Holarctic, probably Palearctic origin. In South America it is accompanied and partly preceded by peculiarly modified and somewhat less progressive genera, *Hippidion* and *Onohippidion,* in which influence of North America predecessors is apparent; but the modification seems to be partly due to South American environment as well. We would conclude that the Middle Pampean is later than the base of the Pleistocene, but how much later would be difficult to say.

On the other hand, the Ground Sloths are of South American origin. The genus Mylodon appears in the Monte Hermoso beds, below the Pampean in South America, in North America in the Lower Pleistocene, and is accompanied here by *Megalonyx,* less progressive but modified peculiarly, appearing somewhat earlier, and bearing almost the same relations to *Mylodon* that *Hippidion* does to *Equus. Megalonyx* also appears earlier in North America (Blanco or Middle Pliocene) and is unknown in South America, although evidently descended from the Miocene Megalonychidæ, just as *Hippidion* is from the Miocene *Pliohippus* of North America. From this we would conclude that the Monte Hermoso beds underlying the Pampean are older than our Lower Pleistocene. By comparing this result with that derived from the Equidæ the equivalence of the Pampean with the Pleistocene seems assured.

A similar method of treatment of the various groups common to the Pampean and Pleistocene fauna of South America and Holarctica yields confirmatory results. These are:

Canidæ, Ursidæ, Felidæ, Procyonidæ, Cervidæ, Camelidæ, Equidæ, Tapiridæ, Mastodontidæ, Muridæ, etcetera, of Holarctic origin.

Erethizontidæ, Mylodontidæ, Megalonychidæ, Glyptodontidæ, Tatusiidæ, etcetera, of Neotropical origin.

It is not often that so fair an opportunity as this is afforded for correlation in far distant regions. More commonly the isolation of the region has prevented or impeded faunal interchange; the migration has not been faunal, but more or less sporadic, and all in one direction; and local adaptive radiation has caused progressive evolution, the resulting parallelism and convergence adding new difficulties to the correlation problem. It is doubtful whether such correlations can ever be correctly and accurately made except on diastrophic criteria, and for this method our data are not yet sufficient.

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PRE-CAMBRIAN STRUCTURE OF THE NORTHERN BLACK HILLS, SOUTH DAKOTA, AND ITS BEARING ON THE ORIGIN OF THE HOMESTAKE ORE BODY[1]

BY SIDNEY PAIGE

(Read before the Society December 30, 1912)

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INTRODUCTION

It is the purpose of this paper to suggest the hypothesis that the Homestake ore body is *in the main* a replacement deposit in a calcareous slate series, and that it owes its position to the presence of a strong fault and its form to its replacement character and to structural factors.

These conclusions are not stated as final, as further study of this problem is contemplated. Paleozoic and Tertiary rocks cover and igneous intrusions in places obscure observations, while the examination underground was very incomplete.

The Black Hills are an oval-shaped mountainous tract, trending nearly north, on the extreme western edge of South Dakota. Physiographically this mountainous tract is the dissected core of an oval-shaped domical uplift which involves rocks as late in age as Tertiary.

Erosion has stripped the cover from this oval dome and etched the underlying basement series of pre-Cambrian schists.

It is with this underlying pre-Cambrian basement series that this paper has to do, and solely with that portion confined to the northern end of the structural dome.

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[1] Published with the permission of the Director of the U. S. Geological Survey.
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These pre-Cambrian rocks in the extreme northern part of the hills are only partially exposed. They occupy an elongate area 8 or 9 miles in length, lying in a northwest-southeast position. The area is surrounded and partly covered by Paleozoic sediments; also it contains many late intrusive rocks, which break the continuity of the schists and obscure structural relations.

Rocks

The pre-Cambrian rocks comprise quartz-biotite schists, garnetiferous schists, slates, calcareous slates, limestones or dolomites, conglomerates and quartzites, and a variety of intermediate types depending for their character on slight original differences in composition. The whole is the metamorphic equivalent of a sedimentary series of no mean proportions.

These rocks are, in broad terms, distributed in two divergent groups (see sketch map, figure 1, page 295). The one, an eastern group, striking slightly east of north, comprises from east to west, and, so far as dips are concerned, from top to bottom, biotite schist, with thin bands of slate, a quartzite, garnetiferous schist, a quartzite, slates, a quartzite conglomerate ("upper" conglomerate), a band of slate, a quartzite conglomerate ("lower" conglomerate), and last a calcareous series grading downward into black slate. The other, the western group, striking west of north, comprises from east to west, first, an alternating series of black slates and quartzites, and next a thick series of slates and phyllites containing some thin calcareous beds and some quartzites, and to the west some dominantly quartzitic beds.

The divergent strike of these two somewhat similar groups of rocks is explained by a fault-line which passes about north 20° to 30° west through the town of Lead, and which, though its precise location is with difficulty determined, is an actual boundary between the two groups.

Structure

There is a general structure which prevails over this entire region, namely: The rocks are closely folded and have steep isoclinal dip to the eastward.[2] As stated, however, in the last paragraph, a strong fault divides the region into two structurally opposed parts.

It is the strike of the axes of the major folds which determines the trend of the rocks within these parts. Minor folds imposed on the limbs of the great folds create strikes at variance with the major strike, but so closely are the rocks appressed that the strike of these minor folds is seldom greatly different from the strike of the major folds. The major folds and also the minor folds, so far as determined, pitch southward.

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[2] There are exceptions in relatively small areas.

The means by which these several structural features are determined may be here pointed out. Such a statement will also serve to explain why only the major structural relations are determinable.

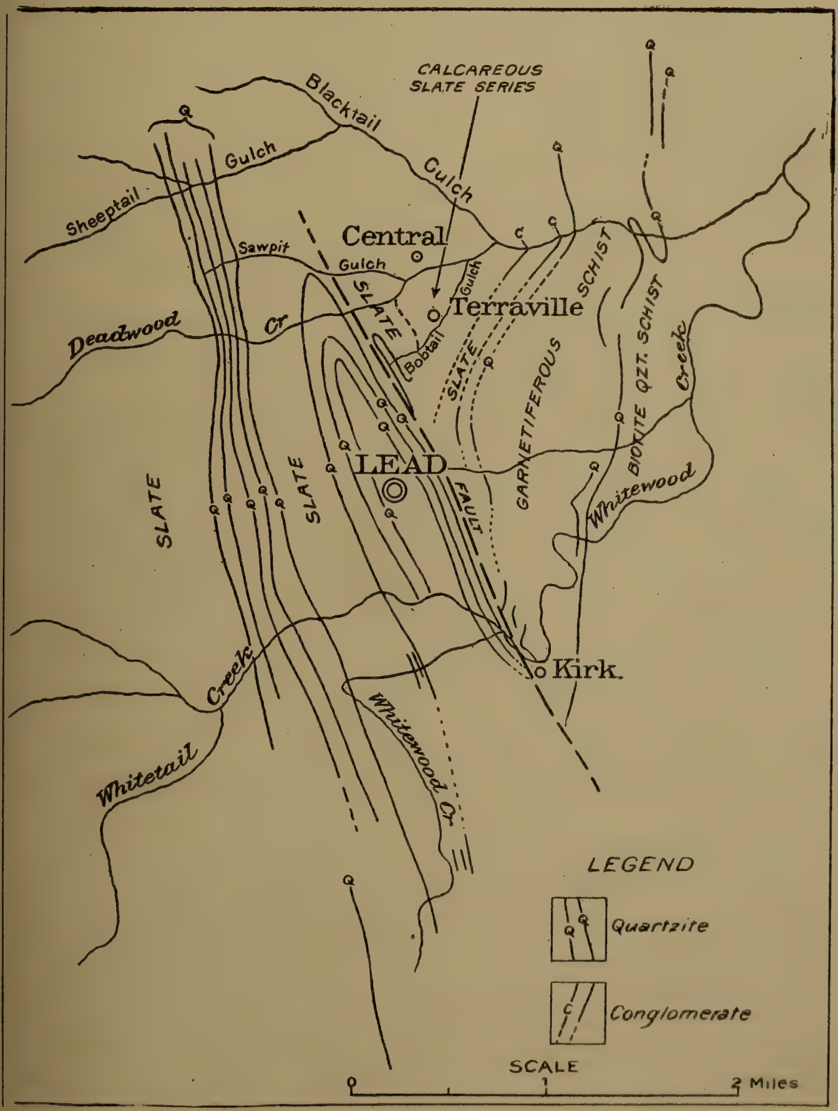
CALCAREOUS SLATE SERIES
Blacktail
Gulch
Sheeptail
Gulch
Central
Sawpit
Gulch
Deadwood
Cr
SLATE
Terraville
Gulch
Bobtail
SLATE
SCHIST
GARNETIFEROUS
BIOTITE QZT. SCHIST
Creek
Whitewood
LEAD
FAULT
SLATE
SLATE
Kirk
Creek
Whitetail
Whitewood Cr.
LEGEND
Quartzite
Conglomerate
SCALE
0
1
2 Miles

FIGURE 1.—*Sketch Map showing Pre-Cambrian Structure in northern Black Hills*

Within this series of schists there are only a few stratigraphic members which are sufficiently persistent and distinctive to permit tracing along the strike with complete assurance that a definite horizon is being followed. Such beds are the quartzites and the conglomeratic quartzites. But, fortunately, the results obtained by following these traceable beds are checked by the differences in lithologic character of certain other beds or groups of beds—such, for example, as the garnetiferous schists, the limestones, and the slates, which maintain their structural relations to the quartzites and quartzite conglomerates over considerable distances.

In general, folding within any of the homogeneous units—the garnetiferous schists, the slates, or the limestones—can not be deciphered with sufficient definiteness to be shown on a map, though abundant evidence is presented in the field to indicate that such minor folds are present.

By pursuing the method of tracing the quartzites and quartzite conglomerates, the following facts were established: In the western division a group of at least five quartzites were traced more or less continuously from the divide north of Sheeptail Gulch to a point east of Whitewood Creek, north of Englewood. Many attempts were made to discover if the quartzites of this series were duplicated by folding. All such attempts ultimately failed to show a repetition of beds and apparent inconsistencies of outcrop, such as sudden termination of beds, and sudden minor changes of strike were found to be due to either a change in the resistance of the bed to forces of weathering or to minor changes of stratigraphic succession, which are normal when sandy beds are involved.

Less than half a mile east of this group of quartzites a second group of similar beds were traced. Here, however, the results indicate a closely compressed synclinal fold—synclinal because the general pitch of the folding is southward and because this fold apexes to the north. As nearly as could be determined, the outer quartzite of this series turns or apexes on the south side of Sawpit Gulch about one-half mile west of the town of Central. The turning points of the remaining quartzites are naturally farther south, but were not determined.[3]

The outcrop of the quartzites forming the two limbs of this fold may be traced. The eastern set are cut off at Kirk by the great fault. The western set, at least the westernmost member, may be said to maintain its integrity for three miles, though it is not exposed continuously throughout this distance.

If, now, the beds east of the fault-plane are examined in more detail, the following relations are of importance: The series as a whole strikes north-northeast and, except in one region to be described later, dips at a high angle to the east. This series is structurally discordant with the rocks on the west side of the fault, and as they differ lithologically from those rocks no hypothesis of folding will explain their observed relations.

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[3] Porphyry intrusions, overlying Cambrian strata and forest cover combine to conceal outcrops of pre-Cambrian strata.

The most important member or members within this series of rocks, economically speaking, are the limestones.[4] They may be regarded as a part of a calcareous slate series and grade downward, through a calcareous slaty phase, into very thin-bedded siliceous black slates. Their lower limits are thus ill-defined. Their upper limit, fortunately, lies only a short distance stratigraphically below the "lower" conglomerate. These limestones are best exposed at the junction of Deadwood Creek and Blacktail Gulch, particularly in the wagon-road cut descending from Terraville, where it turns westward to descend into Deadwood Creek. Fine exposures are likewise to be found in the railroad cut just east of the mouth of Bobtail Gulch, and also in Bobtail Gulch on its eastern side below the lower stamp-mill.

The top of these limestones[5] is believed to pass from Deadwood Gulch, just below Blacktail Gulch, southwestward to a point about 1,800± feet south of the Terraville bridge, where the series is cut off by the fault. The base of the series is not so readily located. Impure limestone may be found on the wagon road in Terraville at the upper stamp-mill, and the lean ore exposed in the De Smet cut, forming a perfect narrow synclinal trough, proves to be a decidedly calcareous or dolomitic rock.[6] Calcareous beds in the slate series were also observed in the town of Central, nearly opposite Sawpit Gulch, and calcareous slates were found still farther west behind the mine hoist.

It is in this region (near Central), at the base of the limestone series, that the rule of eastward dip described above does not apply, for a short distance east of the probable location of the fault-plane westward dips may be seen, and from here down to Blacktail Gulch the rocks seem to be thrown into a low, much disturbed anticline, which, combined with the transitional character of the limestone series, makes it doubly difficult to establish a basal boundary.

Notwithstanding this obscurity, the fact remains that a calcareous series of rock strikes at an angle into and is cut off by a belt of quartzites, and this at the apex of the main Homestake ore body. This discordance of strike demands the presence of a fault. The top of the limestone series may be regarded for stratigraphic purposes as just below the "lower" conglomerate, and the "upper" conglomerate lies only about 350 feet above the "lower." It is of particular interest, therefore, to trace or pick up these conglomeratic beds along their strike to the southwest. It is believed that both of these horizons have been recognized in the Caledonia open cut, though the stratigraphic distance between them seemed at this place to be less than 350 feet. Surface oxidation of the pyritized beds in which this cut is opened, of course, gives a different appearance to the conglomerates, yet their dominant characteristics—quartzitic nature and flattened pebbles—can be recognized. To the southwest these beds (the "upper" conglomerate) may again be observed on the eastern rim of the great Homestake open cut and may be traced down this rim to the machine shops on the edge of the town of Lead. If the stratigraphy, which has been barely outlined above, proves correct, it is obvious that the "lower" conglomerate must lie near or just below the bottom of the great open cut and the ore body would then coincide with the limestone. A synclinal trough of ore exposed in the De Smet cut is particularly interesting from a structural standpoint. It is suggested that this particular synclinal fold is but a minor one imposed on the western limb of the larger anticlinal referred to above. It pitches southward and the outcrop of its eastern limb should theoretically be traceable on the surface were it not interrupted by porphyry intrusives. It is believed at present that the fault cuts this fold and the larger anticlinal somewhat as illustrated in the purely diagrammatic figures on page 298.

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[4] The word "limestone" is used in all parts of this paper as a convenient term to express the idea that *carbonate* rocks are involved. Dolomitic limestones are present.

[5] Paleozoic cover, Tertiary cover, porphyry intrusions, and float, all obscure relations.

[6] Specimen examined microscopically was obtained south of Terraville bridge.

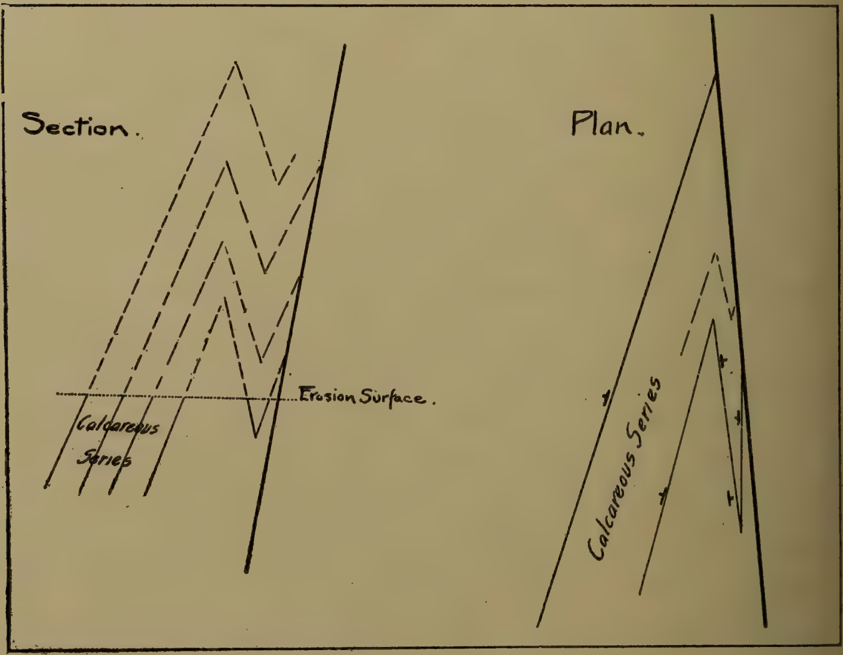

FIGURE 2.—*Diagrammatic Plan and Cross-section*

Such an interpretation accounts for all the facts at present known.

POSITION AND FORM OF THE ORE BODY

The form and position of the surface croppings of the Homestake ore body may be gathered from a study of the open cuts. It is observed that there are two parts: a wide part, that to the south (the great open cut at Lead), and a narrow part, that to the north, terminating in the De Smet cut on the southern rim of Deadwood Creek.

The narrow portion begins to spread and merge into the wide portion at a point where stratigraphic work indicates the presence of the main body of the calcareous series. The narrow portion appears to be a single calcareous bed thrown into a sharp fold well exposed as a narrow synclinal trough in the northern end of the De Smet cut.

The western boundary of these surface exposures is a relatively straight line and is believed to be, for reasons already set forth, a fault-plane.

The outcrop of the Caledonia ore body has been shown to coincide very nearly with the outcrop of a part of the calcareous series. The strike is directly toward the main Homestake ore body; in fact, a portion of the two open cuts are very close together.

Beneath the surface the form and position of the ore body is even more significant. The wider portion, on a given level, is delimited in certain definite ways. First, on the western or footwall side by a relatively straight line—the fault-line; second, on its southern end by a number of narrow fingers, which examinations show to be actual folds—that is, the ore is sharply cut off by wall rock which curves around it; and, third, on the north-northeastern side—that is, in the direction of strike of the rock series—by indefinite fading away of ore. The inference is that here a definite series of beds striking north-northeast have been folded, cut off by a fault, and mineralized.

The ore body plunges in the direction of the intersection of the fault-plane with the steeply dipping beds, and at each succeeding level is capped by a greater thickness of barren rock. The Caledonia ore body pitches *with the dip*—that is, the replaced beds are cut by no fault-plane. Its northern extension is taken to be limited by the distance from the fault-plane that solutions were able to replace limestone, its southern extension by late igneous intrusion, which separated the ore body from the main mass along the fault.

CHARACTER OF THE REPLACED ROCKS

It has been implied in the preceding paragraphs that the ore body is related to a definite set of beds,[7] and in describing surface relations it was pointed out that the outcrop of the main lode corresponded to the position of a calcareous series as determined by stratigraphic work. Specimens were collected underground and examined microscopically, with a view to determining three points: the nature of the beds where ore graded into rock too poor to extract, the nature of various wall rocks, and the nature of the ore.

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[7] The main ore body is here referred to. There are probably other ledges occupying mineralized slate bands.

It is not desirable to describe in detail here the results obtained, but the essentials are as follows: A number of specimens collected on the north-northeast side of the ore body (from various levels), where the ore graded into country rock, proved to be distinctly calcareous. They would be termed calcareous or dolomitic slates or schists and carry 50 per cent or more of carbonate. The walls where the ore body is clearly defined are either siliceous slate or quartzite, or, as found in one case 50± feet from the footwall[8] of the Caledonia ore body, a decidedly calcareous or dolomitic schist. An examination of several specimens of the ore proper shows an abundance of carbonate replaced by silicate minerals, sulphides, the oxides magnetite and specularite, and quartz. Prominent among the silicates are the iron amphibole[9] cummingtonite, phlogopite, chlorite, and some biotite. Among the sulphides are pyrite and pyrrhotite. The form of the cummingtonite was significant in that it possesses that incomplete crystallization of individuals and poikilitic inclosure of other minerals which has been described as occurring in replaced limestones.[10] That the silicate minerals do not show a noteworthy amount of calcium, but are magnesian silicates, suggests that the replaced beds were dolomitic[11] and indicates one of many chemical problems awaiting solution.

SUMMARY

It is suggested that the main Homestake ore body owes its origin to the presence of a strong fault and the subsequent mineralization of a calcareous series, its form being that which would be taken if a folded sedimentary series were cut by a fault and replaced by solutions arising along the fault. The particular form which observed facts would require of such a calcareous series as is present agrees with the form of the ore body as determined by mining. Microscopic examination of ores and wall rocks, as far as carried on, supports this hypothesis.

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[8] A narrow dike at the place.

[9] The amphibole observed agrees in its optical properties with cummingtonite described by W. J. Sharwood: "Analyses of some rocks and minerals from the Homestake mine, Lead, South Dakota." Economic Geology, vol. 6, No. 8, p. 729.

[10] F. L. Ransome: Geological and ore deposits of Bisbee quadrangle, Arizona. Professional Paper No. 21, U. S. Geological Survey, p. 130.

Waldemar Lindgren: The copper deposits of the Clifton-Morenci district, Arizona. Professional Paper No. 43, U. S. Geological Survey, pl. vii, A. C. D., pl. xv.

[11] Analyses have proved this to be the case.

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PETROLOGY OF A SERIES OF IGNEOUS DIKES IN CENTRAL WESTERN VIRGINIA[1]

BY THOMAS L. WATSON AND JUSTUS H. CLINE

(Presented by title before the Society December 30, 1912)

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[1] Manuscript received by the Secretary of the Society, February 3, 1913.

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INTRODUCTION

Although the Great Valley region, extending from Pennsylvania to Alabama, inclusive, and lying immediately northwest of the eastern crystalline province, has been the subject of serious study by many geologists, the essential though not entire absence of igneous rocks in general is noteworthy. There are very few recorded occurrences of igneous rocks found within the limits of this vast areal extent and thickness of Paleozoic sediments. Naturally, therefore, the discovery of new occurrences of igneous rocks within this region, although of common types, is of importance; but when igneous rocks, belonging to types hitherto unknown to the region and by no means common elsewhere, are found, their geologic occurrence and petrologic character become of still greater scientific interest and importance.

The occurrence of igneous rocks as dikes in the Paleozoic sediments of middle western Virginia, west of the Blue Ridge, has been known for many years. Fontaine,[2] John L. and H. D. Campbell,[3] Darton,[4] and Watson[5] have noted and described dikes of igneous rocks in this region. Only two types, however, have hitherto been recognized, the most frequent and common one of which has been diabase including basalt. In addition to diabase, Darton has noted and described the occurrence of granite-felsophyre in Alleghany County, Virginia, and several dikes of basalt near the State line on the north, in Pendleton County, West Virginia.

Recent investigations by the writers, assisted by Prof. F. J. Wright, of Bridgewater College, Virginia, have resulted in the discovery of numerous other dikes of diabase in Augusta, Rockbridge, and Rockingham counties, Virginia, and in addition to diabase four igneous rock types hitherto unknown to the region, the four new types—quartz gabbro, nepheline syenite, camptonite, and teschenite (feldspar monchiquite)—occurring as a series of complementary dikes intimately and interestingly associated with each other, cutting the Shenandoah group of limestones and later formations, including the Mississippian sandstones of Little North Mountain. The dikes closely parallel each other and can be traced for long distances across the Valley group of limestones and the later rocks of the Alleghany Ridges to the west, but they have not been traced farther east than the northwest base of the Blue Ridge. The rocks are of especial interest, since several types mark the first occurrence yet noted in the southeast Atlantic States.

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[2] The Virginias, 1883, vol. iv, p. 45.

[3] McFarlane's Railway Guide, 1890, p. 361.

[4] Amer. Jour. Sci., 1890, vol. xxxix, pp. 269–271; ibid., 1898, vol. vi, pp. 305–315. Monterey Folio, No. 61, Virginia-West Virginia, U. S. Geological Survey, 1899.

[5] Amer. Jour. Sci., 1907, vol. xxiii, pp. 89-90.

The purpose of this paper is to record the distribution, occurrence, and relations of the dikes; describe their microscopic petrography, based on the study of many thin-sections; discuss their chemical composition, based on complete chemical analyses of the different types, and from their calculated norms indicate the position of the rocks in the quantitative system.

The writers do not claim that this study includes the discovery and location of every dike or exposure of igneous rock within the limits of the region; on the contrary, we are convinced that other dikes will probably be found. It is believed, however, that the investigation has been sufficiently detailed to warrant the statement that the discovery of additional types of igneous rocks within the limits of the region is remote, and that in the event of additional dikes being discovered, which is more than probable, they will be found on careful petrographic study to belong to one of the several types recognized and described in this paper.

For the complete and accurate chemical analyses of the rocks described in this paper the writers wish to make grateful acknowledgment to Mr. J. Wilbur Watson and Mr. J. G. Dinwiddie, instructors in chemistry in the University of Virginia.

RÉSUMÉ OF THE GEOLOGY OF MIDDLE WESTERN VIRGINIA

No attempt is made here at a complete discussion of the geology of middle western Virginia,[6] nor does the present problem warrant it. Only those features of the general geology, therefore, which are essential to the understanding of the relations of the igneous materials to the geology of the region will be considered. Structurally, the geology of the region is quite varied and in places complex because of faulting associated with folding.

The rocks of the region into which the dikes of igneous material have been intruded are entirely of sedimentary origin and include strata ranging in age from Lower Cambrian to Mississippian (Lower Carbonifer-

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[6] For a more complete discussion of this region the reader is referred to Bulletin 11-A of the Virginia Geological Survey, 1909.

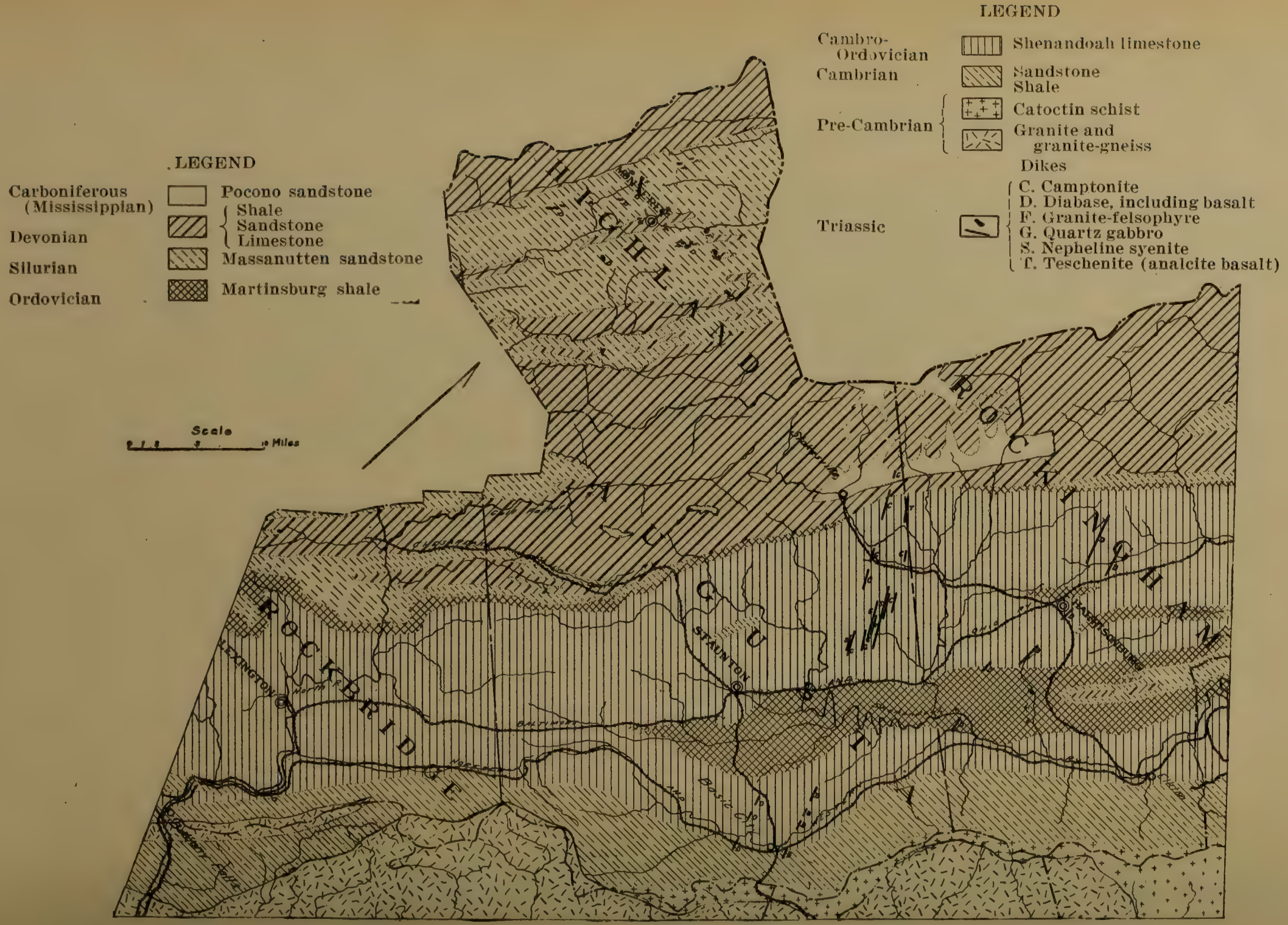
LEGEND
Carboniferous (Mississippian)
Pocono sandstone
Devonian
Shale
Sandstone
Limestone
Silurian
Massanutten sandstone
Ordovician
Martinsburg shale
Scale
10 Miles
LEGEND
Cambro-Ordovician
Shenandoah limestone
Cambrian
Sandstone
Shale
Pre-Cambrian
Catoctin schist
Granite and granite-gneiss
Dikes
Triassic
C. Camptonite
D. Diabase, including basalt
F. Granite-felsophyre
G. Quartz gabbro
S. Nepheline syenite
T. Teschenite (analcite basalt)
HIGHLAND
MONTEREY
ROCKINGHAM
HARRISONBURG
AUGUSTA
STAUNTON
ROCKBRIDGE
LEXINGTON
Basic City

FIGURE 1.—*Geological Map of middle western Virginia*

ous). They include shales, sandstones, and limestones, which show considerable variation in composition and appearance. They have suffered more or less metamorphism and in consequence are frequently much changed, both lithologically and structurally. They represent the entire sedimentary column of the Shenandoah Valley and the Alleghany Ridges physiographic provinces in which the dikes are found. The geology of the region is shown on the accompanying map, figure 1.

The formations recognized in central western Virginia are given in the subjoined table.[7]

Paleozoic:		Feet.
Carboniferous (Mississippian)	Pocono sandstone	700
Devonian	Hampshire sandstone	1,800
	Jennings shale and sandstone	3,800
	Romney black shale	1,300
	Monterey sandstone	300
	Lewistown limestone	1,050
Silurian	Lewistown shaly limestone	
	Rockwood sandstone, etc.	900
Ordovician	Massanutten sandstone	600
	Martinsburg shale	1,400
Cambro-Ordovician	Liberty Hall limestone	1,000 ±
(Shenandoah group.)	Murat limestone	150
	Natural Bridge limestone	3,500
	"Buena Vista" (Watauga) shale	900
	Sherwood (Shady) limestone	1,800
Cambrian	Lower Cambrian quartzite	800
	Lower Cambrian shale and quartzite	3,000

The Appalachian revolution closing the Paleozoic era of sedimentation in western Virginia resulted in widespread folding, accompanied in many places by faulting, chiefly of the thrust type, of the sedimentary formations listed above. This period of deformation, as is shown later in this paper, occurred prior to that of the intrusion of igneous material as dikes. The axes of the folds, as well as the trend of the major faults, extend in a general northeast-southwest direction.

Folding and faulting of the Paleozoic rocks of this region, together with the long period of subsequent erosion, have resulted in the production of nearly parallel ridges, which owe their existence to the resistant character of the rocks. The drainage of the region is well adjusted to the rock structure, as shown by the streams having established their courses largely on the soft rocks, shale and limestone, which form the valleys, and having avoided the harder and more resistant rocks, such as sandstone and quartzite, which are ridge-forming.

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[7] Thomas L. Watson: A geologic map of Virginia. Virginia Geological Survey, 1911.

Distribution and geologic Field Relations of the Dikes

The dikes of igneous rocks forming the subject of this paper are entirely limited in occurrence to the counties of Rockbridge, Augusta, Rockingham, and Highland, which are located in the extreme west-central division of Virginia, partly in the Shenandoah Valley and partly in the Alleghany Ridges physiographic provinces. None of the dikes have been observed to extend farther east than the northwest foot of the Blue Ridge, where they have been noted intersecting the Potsdam group of Cambrian age. The accompanying geologic map, figure 1, shows the distribution of the dikes. In certain areas of the Alleghany Ridges, especially in the vicinity of Monterey,[8] Highland County, the dikes are numerous.

Of the six rock types recognized, diabase is the most abundant and has the widest distribution, being observed at intervals over the entire region where the igneous material occurs. The minimum distance from the most southerly to the most northerly exposure of the diabase is about 60 miles, and for an east-west distance of about 50 miles, extending from the foot of the Blue Ridge almost to the Virginia-West Virginia boundary. Exposures of diabase are noted at numerous points between these extremes. On the other hand, the dikes of granite-felsophyre are restricted in distribution to a limited area in the vicinity of Monterey, Highland County, while those of nepheline syenite, teschenite, and camptonite, together with a single dike of quartz gabbro, occur in a closely associated series confined within comparatively narrow limits in the northern part of Augusta County. The distribution of the dikes is shown on map, figure 1.

In no case has the igneous rock been observed as a continuous exposure at the surface for any great distance, but the exposures appear at irregular intervals in lines which either extend entirely across the Valley province or in shorter parallel lines to these. Thus far the maximum distance for which a single exposure has been traced does not exceed 1.5 miles, and as a rule the exposures are very much shorter, frequently being measured by only a few yards. So far as could be determined, the dikes over

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[8] N. H. Darton: Amer. Jour. Sci., 1890, vol. xxxix, pp. 269–271; ibid., 1898, vol. vi, pp. 305–315.

Monterey Folio, No. 61, Virginia-West Virginia, U. S, Geological Survey, 1899,

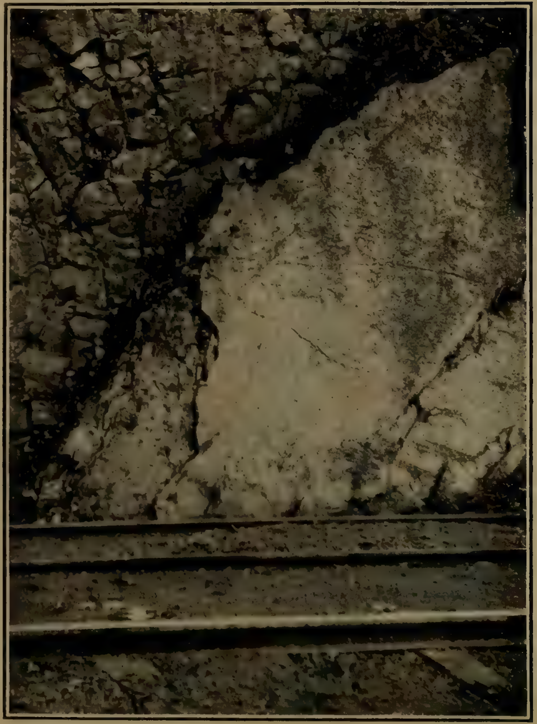

FIGURE 1.—VIEW OF DIKE NORMAL TO DIRECTION OF STRIKE
Upper half shows checkered structure from jointing; lower half (light color) shaley limestone

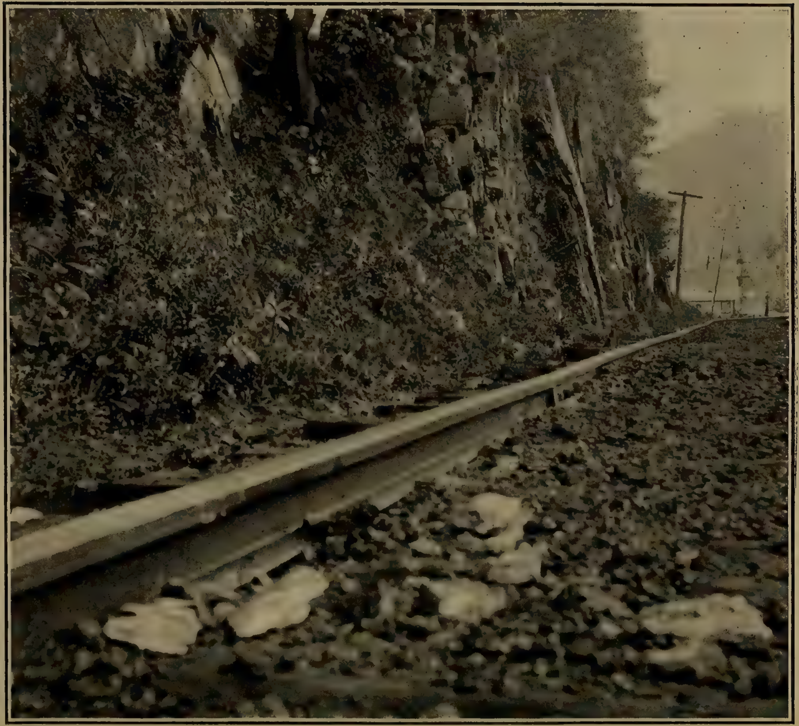

FIGURE 2.—VIEW OF SAME DIKE AS FIGURE 1
Exposed in direction of strike of dike and the inclosing shaley limestone

DIABASE DIKE EXPOSED IN RAILROAD CUT AT LOCH LAIRD, ROCKBRIDGE COUNTY, VIRGINIA the entire region maintain a general similarity in direction of strike to the northwest. In other words, they apparently lie in the northwest quadrant, but naturally exhibit varying degrees of strike within the limits of the quadrant. An exception to this was noted in the dike at Loch Laird, which diabase has been intruded between nearly vertical beds of calcareous shale belonging to the Shenandoah group of limestones (see plate 7). Whether or not this represents one of a series of outcrops of the same dike across the valley in that latitude is not known. Farther north a single occurrence of this kind is always accompanied by a number of others distributed in relation to it in the manner described above. A second exception is noted in some of the dikes of the Monterey district in Highland County, where possibly they are aligned in a north-northeast direction.

In width the dikes vary from 4 feet up to 80 feet, with a probable average of about 20 feet. They may be readily traced by the character of their residual soil and by the presence of abundant large and small weathered boulders, so thickly strewn over the surface along the direction of strike as to make agriculture impossible in many cases (see plates 8 and 9). Usually the boulders of the basic rocks (diabase, camptonite, and teschenite) exhibit well rounded form from spheroidal weathering (see plate 8, figures 1 and 2). The basic dikes as a rule exhibit but slight or no topographic expression, while the more acid rock nepheline syenite occupies the crests of ridges and is exposed both by a line of low weathered reefs and loose masses that are only partially rounded (see plate 9, figure 1).

With the single exception noted above of diabase, the distribution of the dikes of igneous rocks and their structural features bear no evident relation to the dominant Appalachian structure. The lines of outcrops, as well as the individual outcrops themselves, strike in a direction nearly normal to the axes of the structure of the Paleozoic sediments. As may be seen by consulting the accompanying map, figure 1, the dikes maintain fairly close parallelism with each other, and, moreover, they sustain the same relations to the inclosing sedimentary rocks regardless of their lithologic character and the attitude of the beds.

To the writers it seems hardly reasonable to assume that the above arrangement of the dikes—their direction of strike and the structure of the inclosing rocks—is fortuitous. It is rather to be inferred that their general uniformity in direction of strike is the expression of some structural feature developed in the Shenandoah group of limestones and other later formations of the region at some period postdating the folding and faulting of the rocks from the Appalachian revolution which closed the Paleozoic era. The tendency of dike control by joints and faults is a matter of record in many cases and has been observed in near-by regions, namely, in the Richmond coal basin by Shaler and Woodworth[9] and in the granite and sandstone areas of North Carolina by Watson and Laney.[10]

The investigations by the writers of the Virginia region suggest to them that the dikes which form the subject of this study have followed fissures along lines of normal faulting and probably jointing which exhibit the same direction of strike, developed contemporaneously with the period of deformation resulting in the production of faults in the Triassic areas of the eastern United States. Normal faults in the sedimentary rocks west of the Blue Ridge correlated by the writers with the Triassic period of deformation have been observed, and further careful study will doubtless reveal them in considerable numbers. In the Cambrian areas immediately east of the Blue Ridge in Virginia, where conditions are favorable for observation, normal faulting in at least two directions has been observed by the writers which equals in development that of the Triassic areas near by. Evidence of the period of deformation which resulted in the production of normal faults in these Cambrian areas indicates to the writers that which was productive of similar structure in the Triassic areas. It would seem probable, therefore, that normal faulting of the Triassic beds was developed by disturbances more widespread in the Appalachian region than has been previously supposed.

CONTACT METAMORPHISM

Although the dominant type of sedimentary rocks intruded by the dikes is limestone, and although the igneous bodies are of fairly good size, measuring in some instances as much as 80 feet in width, no apparent contact metamorphism has been noted. Angular fragments of the limestones, mostly of very small dimensions, were found incorporated in the substance of some of the basic dikes, which are entirely unaltered and without evidence of the slightest corrosion effect. Sharp contacts between the nepheline syenite and inclosing limestone were observed, where minute dikelets (apophyses) of the syenite occupied fractures in the limestone several inches in length, and small fragments of the limestone were also incorporated in the syenite, but without the slightest manifestation of alteration.

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[9] 19th Ann. Rept. U. S. Geological Survey, part ii, 1897–1898, p. 496.

[10] North Carolina Geological Survey, Bulletin No. ii, 1906, pp. 178-179, 182, 184-187, 241-243.

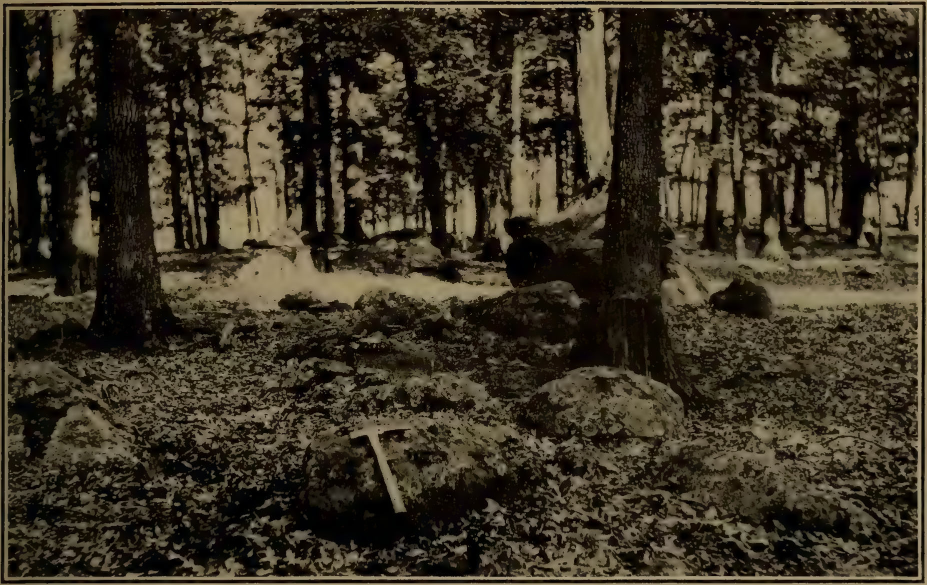

FIGURE 1.—VIEW OF DIKE ON LEONARD FARM CUTTING THE SHENANDOAH GROUP OF LIMESTONES, THREE MILES NORTH OF WAYNESBORO

Showing boulder form of outcrop; taken in direction of strike

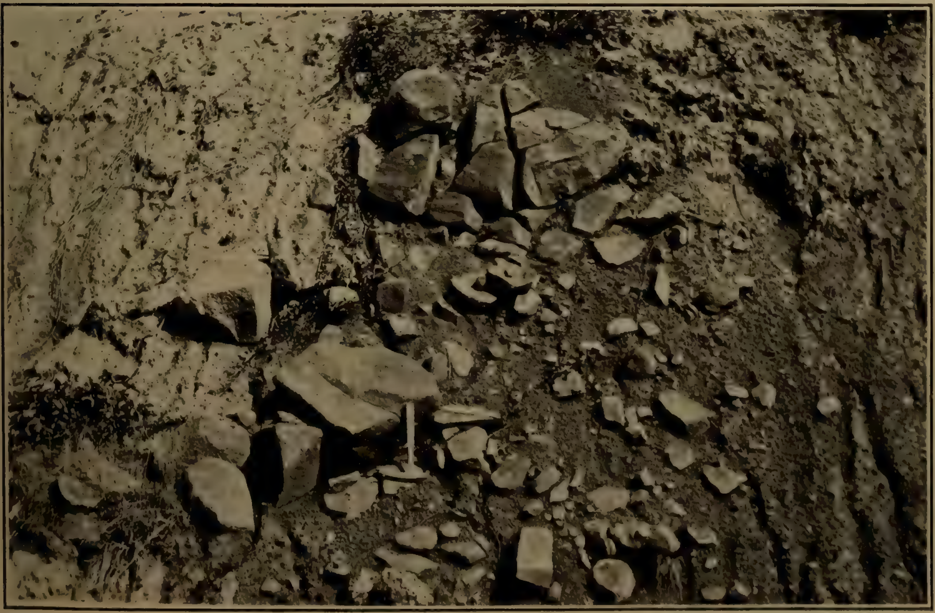

FIGURE 2.—VIEW OF DIKE TWELVE FEET WIDE IN RAILROAD CUT TWO AND A HALF MILES SOUTH OF BASIC

Showing weathering for the entire depth of exposure, 10 feet

EXPOSURES OF DIABASE DIKES NEAR WAYNESBORO, AUGUSTA COUNTY, VIRGINIA

General Petrology of the igneous Rocks

INTRODUCTORY STATEMENT

In the region as previously defined there occurs a variety of igneous rocks of both acid and basic character, the latter greatly predominating. Their only mode of occurrence, so far as observed, is in the form of dikes of variable size. Six types have been recognized, arranged in order of decreasing silica, as follows: (*a*) Felsophyre, (*b*) quartz gabbro, (*c*) nepheline syenite, (*d*) teschenite, (*e*) camptonite, and (*f*) diabase. These are discussed below in the order mentioned. Their gneral distribution and occurrence have already been discussed.

When fragments of the nepheline syenite, teschenite, and camptonite were powdered and boiled with dilute hydrochloric acid, filtered, and the filtrate evaporated, a considerable amount of gelatinous silica was deposited. As developed in the microscopic description of these three rock types, the minerals which yielded to the acid are nepheline in the syenite and analcite in the teschenite and camptonite.

GRANITE-FELSOPHYRE (TOSCANOSE)[11]

General statement.—Thus far this type of rock is restricted in occurrence to a series of small dikes in the vicinity of Monterey, Highland County, Virginia. The dikes of felsophyre are more or less closely associated with those of basalt. Exposures of the acid rock are found to the northeast, north, and northwest of Monterey, in the Alleghany Ridges province, and have been briefly described by Darton, who was the first to note them. They intersect or cut the Shenandoah limestone of Cambro-Ordovician age, the Rockwood (Clinton) shales, and the Romney shales. The specimens collected by Darton were studied microscopically by Keith, who classified the rock as "felsophyre."

Megascopic character.—The rock of these dikes when fresh is light gray or dove-colored and of fine-grained porphyritic texture. Phenocrysts of feldspar (albite and orthoclase), biotite, and augite, developed usually with crystal outlines, are set in a fine-grained, light-gray groundmass. These minerals are subject to much variation in amount, plagioclase and biotite being perhaps the most abundant, while augite usually has scant development. As a rule the plagioclase (albite) phenocrysts are kaolinized and can thus be distinguished from the unaltered orthoclase in hand specimens.

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[11] Most of the facts relating to this type have been abstracted from the work of Darton and Keith: Amer. Jour. Sci., 1898, vol. vi, pp. 305–315; Monterey Folio, No. 61, Virginia-West Virginia, U. S. Geological Survey, 1899.

Microscopic character.—The microscopic petrography of these rocks is comparatively simple. In thin-sections the principal minerals composing the ground-mass are a fine aggregate of feldspar (sodic plagioclase and orthoclase), quartz, biotite, and magnetite. No glass has been identified. Set in this microcrystalline ground-mass are phenocrysts of plagioclase (albite), orthoclase, biotite, and augite, which usually exhibit crystal boundaries. Occasionally some of the phenocrysts of each mineral contain inclusions of the ground-mass. Secondary minerals derived from the original ones by weathering are few in number, comprising chiefly kaolin, chlorite, muscovite, and in sections showing greatest alteration calcite and limonite.

Chemical composition and classification in the quantitative system.—In order to show the composition of this rock, there is given in column I in the subjoined table a chemical analysis made by Dr. W. F. Hillebrand on a typical sample. For comparison, there are added two analyses of related rocks—a trachyte (?) in column II and a granite-porphyry in column III. As may be observed from an examination of the table, the three rocks are remarkably similar in chemical composition. They fall into the same position in the quantitative system[12] and are designated by the subrang name *toscanose.*

Analyses of Felsophyre and related Rocks

(W. F. Hillebrand, analyst)

	I	Ia	II	III
SiO_2	69.56	1.159	69.52	69.68
Al_2O_3	15.52	.152	15.44	14.97
Fe_2O_3	1.67	.011	1.90	0.79
FeO	1.19	.017	0.09	0.34
MgO	0.41	.010	0.17	0.66
CaO	1.20	.021	1.70	2.10
Na_2O	4.46	.073	4.54	3.38
K_2O	4.68	.050	5.04	4.40
H_2O-	0.34	....	0.33	1.10
H_2O+	0.67	....	0.27	0.92
TiO_2	0.31	.004	0.23	0.28
P_2O_5	0.08	.001	0.14	0.17
MnO	0.07	.001	0.08	Trace
BaO	0.10	.001	0.19	0.14
SrO	Trace	....	....	....
Li_2O	Trace	....	....	....
CO_2	None	....	0.17	0.88
S	Trace	....	....	....
	100.26		99.90	99.86

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[12] H. S. Washington: Professional Paper No. 14, U. S. Geological Survey, 1903, pp. 160-161, 164-165.

I. Felsophyre from Monterey Mountain, Highland County, Virginia. Darton and Keith, American Journal of Science, 1898, vol. vi, p. 307.

Ia. Molecular ratios from I.

II. Trachyte (?) from Robbins Branch, Pikes Peak, Colorado. W. Cross, Bulletin 148, U. S. Geological Survey, 1897, p. 163.

III. Granite-porphyry from Wolf Butte, Little Belt Mountains, Montana. L. V. Pirsson, Twentieth Annual Report U. S. Geological Survey, 1900, part iii, p. 499.

The norm, as computed from the analysis in column I, and the position of the Virginia rock in the quantitative system are as follows:

Norm		
Q	22.50	94.43
Or	27.80	
Ab	37.73	
An	5.28	
C	1.12	
Hy	1.53	4.80
Mt	2.32	
Il	0.61	
Ap	0.34	
H_2O	1.01	
	100.24	

Ratios

$$\text{Class, } \frac{\text{Sal}}{\text{Fem}} = \frac{94.43}{4.80} = 19.7 = \text{I, persalane.}$$

$$\text{Order, } \frac{Q}{F} = \frac{22.50}{70.81} = 0.31 = 4, \text{ britannare.}$$

$$\text{Rang, } \frac{K_2O + Na_2O}{CaO} = \frac{122}{19} = 6.42 = (1)2, \text{ toscanase.}$$

$$\text{Subrang, } \frac{K_2O}{Na_2O} = \frac{50}{72} = 0.69 = 3', \text{ toscanose.}$$

Symbol	Name
I. 4. (1)2. 3′.	Liparose-Toscanose.

QUARTZ-GABBRO (TONALOSE (?))

Megascopic character.—Only a single occurrence of this type has been noted in the region. It is found as a single dike, 70 feet wide, in intimate association with the complementary series of dikes of nepheline syenite, teschenite (analcite-basalt), and camptonite, occurring in the northern part of Augusta County. The dike of quartz-gabbro crosses the public road on the Arey farm 1.5 miles south of Milnesville, and can be traced along a north 55° west direction for several hundred yards through the fields on either side of the road. Twenty-five feet south of the quartz-gabbro dike is a parallel one of camptonite not exceeding 10 feet in width, and which can be traced for a somewhat greater distance.

The quartz-gabbro is a dark bluish-gray, medium to fine even-granular (granitoid) rock, which weathers to yellowish brown in color. Both feldspar and quartz are readily distinguishable in hand specimens, with the former greatly in excess. Certain phases of the rock exhibit areas a few inches in diameter in which quartz is apparently equal to or greater in amount than feldspar. The quartz is usually of a bluish opalescent appearance. In addition to the felsic minerals, quartz and feldspar, hand specimens are dotted with pseudomorphs after pyroxene of from 2 to 3 millimeters in diameter. They are bluish-black in color and sometimes resemble in outline the stout prismatic forms of pyroxene. One of the pseudomorphs removed from the rock was found to be strongly magnetic, and when treated with cold dilute hydrochloric acid effervesced freely, clearly indicating its composition to be magnetite and calcite, although the calcite was masked by the greater abundance of magnetite.

Microscopic character.—When examined microscopically in thin-sections, the essential minerals of the rock are found to be plagioclase feldspar (labradorite), orthoclase, quartz, and pyroxene (augite). The rock appears fresh in the hand specimen, but thin-sections under the microscope indicate considerable alteration, which is also shown in the high percentages of CO_2 and H_2O in the chemical analysis below.

The dominant feldspar is labradorite developed in large formless grains and in small lathlike crystals, occupying areas between the larger grains of the rock constituents. A second plagioclase highly sodic and exhibiting multiple twinning is present in minor quantity and is identified as albite. Orthoclase is a constant constituent, but is less abundant than labradorite. It occurs in scattered irregular shaped grains, some of which rival in size labradorite. The feldspars are completely altered in some cases to an aggregate chiefly of minute granular calcite, quartz, and kaolin.

Quartz is an important constituent of the gabbro, but is much less abundant than feldspar. It is developed in anhedral forms of good size interlocked with each other or with feldspar. Liquid and gas inclusions are numerous and frequently needle-like forms of rutile and amphibole are noted, the latter (amphibole) being also observed as inclusions in the feldspar. A peculiar feature of the quartz is its biaxial character, the optic angle being larger than that ordinarily observed in biotite.

Pyroxene, probably originally present as the varieties augite and hypersthene, is partially or completely altered chiefly to calcite and magnetite, with admixed chlorite and quartz. At present only the monoclinic pyroxene, nearly colorless augite, is distinguishable, the alteration products of which are calcite, chlorite, and quartz, with only a little magnetite. The dark, nearly black pseudomorphs observed in the hand specimens and described megascopically above were very probably derived from an iron-rich pyroxene of different variety from the existing one—nearly colorless augite—probably a rhombic pyroxene of hypersthene composition. In thin-sections the pseudomorphs are seen to be composed of a matrix of calcite thickly set with minute crystals of black magnetite, frequently so abundant as to almost entirely mask the substance of the calcite. They exhibit as a rule irregular boundaries, but in some cases a strong tendency toward prismatic forms is indicated. Fractures in the unaltered augite are preserved in the pseudomorphs, but magnetite is essentially absent from them, although it occurs in great profusion in the substance of the other alteration products derived from the augite.

Biotite is developed as a minor constituent in small crystals and flakes, with the usual pronounced pleochroism. Primary or original magnetite in scattered crystals and occasional pyrite make up the other accessory minerals.

Chemical composition and classification in the quantitative system.—The chemical composition of the quartz-gabbro (norite) is shown in the subjoined analysis made by Mr. J. G. Dinwiddie. The large percentages of H_2O and CO_2 given in the analysis clearly show that the rock was not fresh, although it had the appearance of such in the hand specimen.

Analysis and Norm of Quartz-Gabbro, 1.5 Miles South of Milnesville, Augusta County, Virginia

(J. G. Dinwiddie, analyst)

Analysis

	Per cent	Ratios
SiO_2	57.62	.960
Al_2O_3	16.44	.161
Fe_2O_3	2.34	.014
FeO	4.89	.068
MgO	2.53	.064
CaO	6.40	.114
Na_2O	2.91	.047
K_2O	1.52	.016
H_2O-	0.20	....
H_2O+	1.15	....
TiO_2	0.64	.008
MnO	0.27	.004
P_2O_5	0.29	.002
CO_2	3.75	....
	100.95	

Norm

	Per cent	
Q	15.78	76.55
Or	8.90	
Ab	24.63	
An	27.24	
Di	2.07	19.18
Hy	11.97	
Mt	3.25	
Il	1.22	
Ap	0.67	
H_2O	1.35	
CO_2	3.75	
	100.83	

The position of the rock in the quantitative system may be expressed as follows:

Ratios

$$\text{Class, } \frac{\text{Sal}}{\text{Fem}} = \frac{76.55}{19.18} = 3.99 = \text{II, dosalane.}$$

$$\text{Order, } \frac{\text{Q}}{\text{F}} = \frac{15.78}{60.77} = 0.26 = 4\text{, austrare.}$$

$$\text{Rang, } \frac{K_2O + Na_2O}{CaO} = \frac{63}{98} = 0.64 = 3(4)\text{, tonalase.}$$

$$\text{Subrang, } \frac{K_2O}{Na_2O} = \frac{16}{47} = 0.34 = 4\text{, tonalose.}$$

Symbol	Name
II. 4. 3(4). 4.	Tonalose.

NEPHELINE SYENITE (MIASKOSE)

Megascopic character.—Map, figure 1, shows two lines of outcrop of nepheline syenite, which for convenience of description may be designated the north dike and the south dike, located 3½ miles from each other. For purposes of description this designation into a north and south dike is important, since the rock in the two localities exhibits marked differences in texture and mineral composition.

The rock of the north dike, which is prominently developed on the Glick farm, is dove-colored when fresh, strongly resembling many of the associated limestones of the Shenandoah group, for which it might easily be mistaken unless carefully examined. It is porphyritic in texture, with a medium-grained ground-mass, in which a sprinkling of orthoclase crystals, a few hexagonal plates of biotite, and an occasional crystal of hornblende are developed as phenocrysts. The orthoclase is colorless to light gray, has glistening cleavage surfaces, and is idiomorphic in outline. Its crystals attain a maximum of 5 millimeters in length and 4 millimeters in width. The few glistening brown plates of biotite average from 2 to 3 millimeters in diameter, while the occasional phenocrysts of greenish-black hornblende have a maximum length of 7 millimeters. Partially weathered specimens of the rock frequently exhibit a mottled appearance from light gray, irregular areas of dull earthy luster and bluish cast.

The rock of the south dike (plate 7, figure 1) is medium-grained and of light gray color, with a pronounced granitic habit. Its most abundant megascopic constituents are the light-colored minerals, feldspar and nepheline, which can usually be distinguished from each other in hand specimens. The feldspar is generally developed in small prismatic crystals and formless grains, with good cleavage, while the nepheline is developed in irregular grains without noticeable cleavage and possesses an oily luster. Fragments of the latter when isolated from the rock and tested fused easily before the blowpipe and were readily soluble in hydrochloride acid, which on evaporation yielded copious gelatinous silica. Similar results were obtained from tests made on fragments of the rock from the north dike. The only other visible megascopic constituents are a greenish-black hornblende developed in fair abundance in small anhedra, the largest of which measure 3 millimeters in length, and occasional crystals of black biotite.

Weathered surfaces of the nepheline syenite from the south dike are quite interesting in affording beautiful illustrations of differential weathering of the essential rock minerals. The hornblende and feldspar stand out in prominent relief, while the removal by weathering of the less resistant nepheline produces a characteristic pitted surface. The protru-

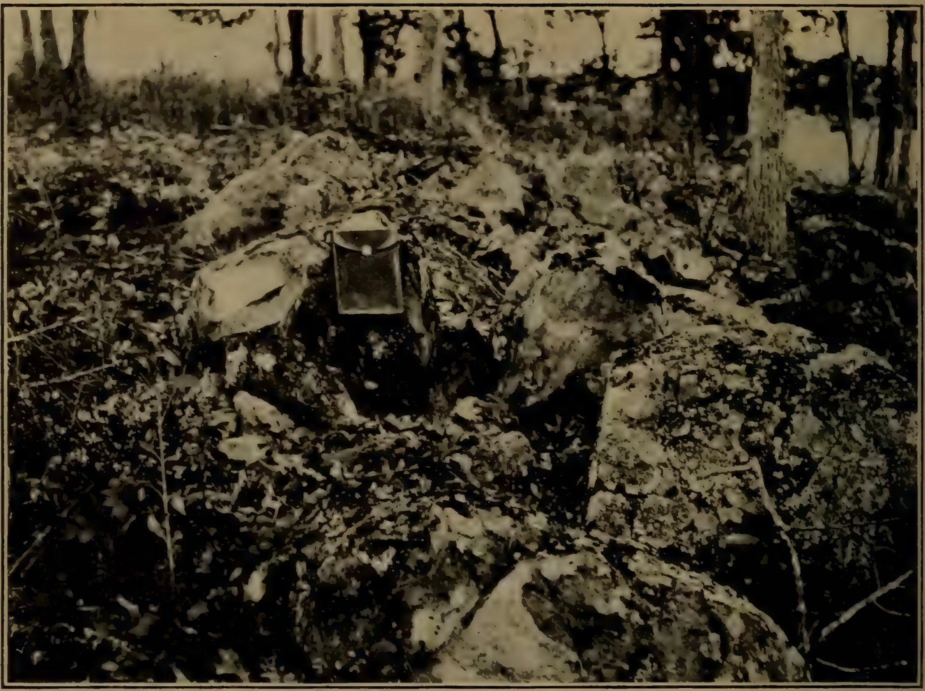

FIGURE 1.—VIEW OF NEPHELINE SYENITE DIKE FIVE MILES SOUTHEAST OF MOUNT SOLON
Showing characteristic bouldery ledge outcrop

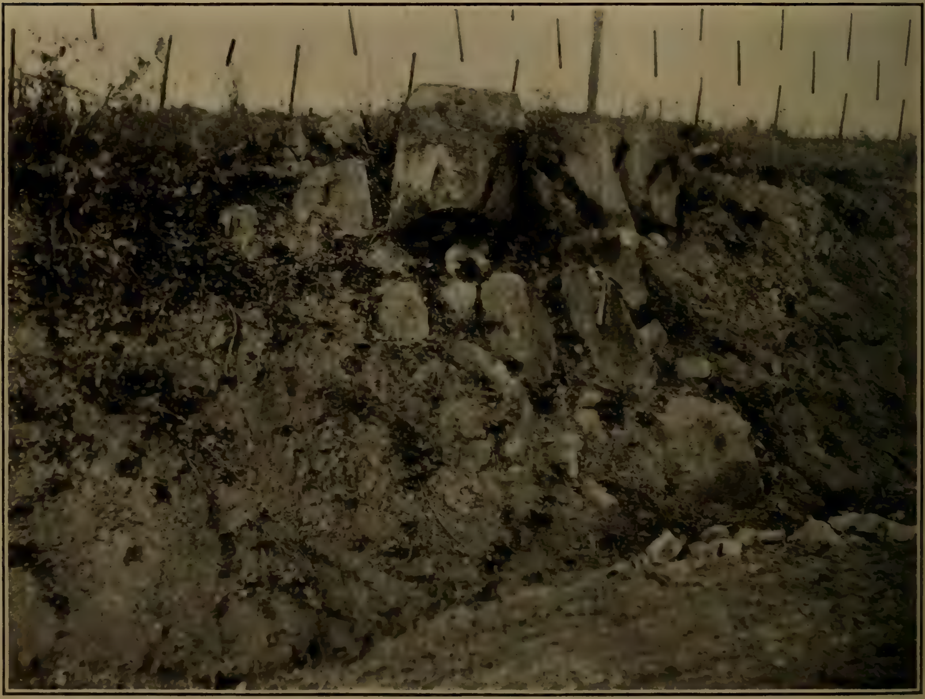

FIGURE 2.—VIEW OF CAMPTONITE DIKE EXPOSED ALONG PUBLIC HIGHWAY ONE MILE NORTH OF MOSSY CREEK
Illustrating spheroidal weathering

EXPOSURES OF NEPHELINE SYENITE AND CAMPTONITE DIKES IN NORTHERN AUGUSTA COUNTY, VIRGINIA sions of light minerals, however, are not composed entirely of the feldspars, since some nepheline occurs in them protected by a network of small feldspar crystals.

Microscopic character.—The mineralogical composition of the two nepheline syenite dikes is essentially the same except that in the north dike the chief mafic mineral is biotite, while in the south dike it is hornblende. In both instances the dark minerals constitute only a small percentage of the rock. The rock consists essentially of the felsic minerals feldspar (orthoclase and albite) and nepheline, which in the thin-sections appear in nearly equal amounts, although the relative proportions vary greatly in different parts of the same section.

The dark constituents, named in order of abundance, are hornblende, biotite, and iron oxide (probably magnetite). An occasional crystal of augite is sometimes developed in the rock of the north dike. Apatite and rutile occur as minor microscopic accessories in the form of inclusions in the other minerals. Alteration of the original minerals has resulted in the development of abundant zeolites, kaolinite, calcite, chlorite, muscovite, epidote, and iron oxide.

The two feldspars, orthoclase and albite, appear to be present in about equal quantity, but are unevenly distributed through the sections. They (especially plagioclase) are very abundant in some parts of the sections and almost absent from others. Albite occurs in idiomorphic lath-shaped forms and in allotriomorphic grains and exhibits characteristic multiple twinning. It was one of the earliest of the essential minerals of the rock to crystallize, and in those areas of the thin-sections where it is especially abundant the lath-shaped forms cutting the other minerals give the rock a pronounced ophitic texture. It is usually clouded with dustlike inclusions. In the north dike, which represents the porphyritic type of the nepheline syenite, orthoclase occurs in two distinct forms, as idiomorphic forms developed as phenocrysts and as allotriomorphic grains in the ground-mass. In the south dike it occurs only as formless grains, exhibiting good cleavage development in two directions. Except hornblende, orthoclase is the freshest mineral in the rock.

Nepheline is an abundant constituent in all the thin-sections; it occurs both as crystals showing rectangular and hexagonal outlines and as masses of irregular outline. Its period of crystallization was earlier than that of the mafic silicate minerals and it frequently cuts or is included in them. The nepheline is usually more or less altered, a very common form of alteration being to fibrous zeolites, whose fibers are arranged nomal to the altered surface. More or less calcite and other secondary products in small particles are often associated with the zeolites, and these may form an aggregate constituting a pseudomorph after the nepheline.

Hornblende and biotite occur as original minerals in all thin-sections studied. In the south dike hornblende is abundant, with rare flakes of biotite, while in the north dike biotite is the most abundant mafic mineral, with rare crystals of hornblende. This constitutes the only important mineralogical difference between the two dikes of nepheline syenite. When hornblende is the chief constituent it occurs in formless grains and crystals with partial boundaries, and in microliths scattered through the colorless minerals or in radiating groups. Hornblende is of green color and pleochroic, x = green, y = light green, and z = greenish yellow. It is associated with brown biotite and green chlorite as alteration products. The inclination of z to c is nearly 10°, and the variety is probably barkevikite. Hornblende in small grains occurs sparingly in thin-sections of the rock from the north dike.

Biotite is partly brown and partly green in color, both colors frequently occurring in the same individual, with the green occupying the outer border. In other cases the crystal is entirely brown or entirely green. The green color in some instances is certainly due to chloritization, and this may possibly be the case in most instances where green is shown. A little iron oxide and a black opaque mineral in irregular shaped forms up to 0.5 millimeter in length, probably ilmenite, occur in all thin-sections, but never in abundance.

Chemical composition and classification in the quantitative system.—An analysis of each of the two dikes of nepheline syenite is given in the table below, the north dike being represented by the analysis in column I and the south dike by the analysis in column II. The two analyses are in very close agreement, and the two rocks, as with nepheline syenite in general, are characterized by medium low silica, high alumina and alkalies, but especially high soda.

Chemical Analyses of Nepheline Syenite from Augusta County, Virginia

	North dike		South dike	
	I	Ia	II	IIa
SiO_2	54.77	.912	53.57	.892
Al_2O_3	21.41	.210	22.46	.221
Fe_2O_3	2.46	.016	1.01	.006
FeO	0.68	.010	0.92	.013
MgO	0.18	.004	0.37	.009
CaO	0.47	.009	1.49	.027
Na_2O	9.53	.153	10.22	.165
K_2O	4.97	.053	5.14	.054
H_2O-	0.17	....	0.43	....
H_2O+	4.61	....	2.97	....

	North dike		South dike	
	I	I*a*	II	II*a*
TiO_2	0.08	.001	0.20	.003
MnO	0.68	.010	0.56	.008
P_2O_5	0.07	.001	0.11	.001
CO_2	0.03	....	0.95	....
S	....	....	0.17	.006
	100.11		100.57	

I. Nepheline syenite from Glick farm, 4 miles east of Mount Solon, Augusta County, Virginia. J. Wilbur Watson, analyst.

I*a*. Molecular ratios from I.

II. Nepheline syenite from property adjoining the Charles Curry farm, 5 miles southeast of Mount Solon, Augusta County, Virginia. J. G. Dinwiddie, analyst.

II*a*. Molecular ratios from II.

The norms computed from the chemical analyses in columns I and II of the table above and the position of the rocks in the quantitative system are expressed as follows:

North Dike (I)

Norm

Or	29.47	90.35
Ab	35.63	
An	1.11	
Ne	24.14	
Ol	0.41	5.07
Di	0.46	
Mt	3.71	
Il	0.15	
Ap	0.34	
H_2O	4.78	
CO_2	0.03	
	100.23	

Ratios

Class, $\frac{\text{Sal}}{\text{Fem}} = \frac{90.35}{5.07} = 17.8 = 1$, persalane.

Order, $\frac{\text{L}}{\text{F}} = \frac{24.14}{66.21} = 0.36 = 6$, russare.

Rang, $\frac{K_2O + Na_2O}{CaO} = \frac{206}{4} = 51.5 = 1$, miaskase.

Subrang, $\frac{K_2O}{Na_2O} = \frac{53}{153} = 0.34 = 4$, miaskose.

South Dike (II)

Norm

Or	30.02	89.20
Ab	25.68	
An	0.56	
Ne	32.94	
Ol	——	7.17
Di	4.18	
Wo	0.46	
Mt	1.39	
Il	0.46	
Ap	0.34	
Pr	0.34	
H_2O	3.40	
CO_2	0.95	
	100.72	

Ratios

Class, $\frac{\text{Sal}}{\text{Fem}} = \frac{89.20}{7.17} = 12.4 = 1'$, persalane.

Order, $\frac{\text{L}}{\text{F}} = \frac{32.94}{56.26} = 0.58 = 6$, russare.

Rang, $\frac{K_2O + Na_2O}{CaO} = \frac{219}{2} = 109 = 1$, miaskase.

Subrang, $\frac{K_2O}{Na_2O} = \frac{54}{165} = 0.32 = 4$, miaskose.

No.	Symbol	Name
I	I. 6. 1. 4.	Miaskose.
II	I. 6(7). 1. 4.	Laugenose-Miaskose.

Out of a total of 46 rocks listed in Washington's[13] tables as *miaskose*, 10 are nepheline syenites.

TESCHENITE OR ANALCITE-BASALT (MONCHIQUOSE (?))

Megascopic character.—The rocks included under this name are very dark gray, almost black in color, and usually porphyritic in texture, although some specimens show very few phenocrysts. Augite and biotite, usually developed with crystal boundaries, and the former always in excess of the latter, are the mafic minerals occurring as phenocrysts. Though less abundant, biotite is more conspicuous as a phenocryst and occurs in larger crystals than augite. The largest biotite crystals attain a size of 1 centimeter in diameter, but most of them average about 1 millimeter. Crystals of augite averaging about 3 millimeters in length exhibit perfectly developed prismatic and pinacoidal faces. The groundmass in which these phenocrysts are set is fine granular, but on close examination both dark and light colored minerals are distinguishable, the former always in excess. With the aid of a pocket lens, a fair abundance of the light minerals can be detected occupying positions between the dark constituents.

One of the most conspicuous megascopic features of some hand specimens of the rock is the large amount of calcite and flesh-colored analcite occupying spherical-shaped areas somewhat abundantly scattered through the rock. Sometimes calcite alone completely occupies the area, less often analcite; but as a rule the two minerals occur together in the same area, when calcite forms the center and analcite the rim or border. The areas rarely exceed 1.5 centimeters in diameter, with an average of about 5 millimeters. These areas probably represent phenocrysts and are similar to those described in detail under camptonite.

Microscopic character.—In thin-sections under the microscope the following primary minerals are seen: Augite, biotite, magnetite, plagioclase and orthoclase feldspar, analcite, and a little apatite. All thin-sections examined show alteration, the secondary minerals named in order of abundance being calcite, zeolites, chlorite, muscovite, and pyrite.

One of the most abundant of the original colorless minerals, analcite, has been completely altered in most of the thin-sections into cloudy aggregates of minute particles of intimately associated calcite, muscovite, and zeolitic substance. Some of the cloudy areas have hexagonal outlines, some rectangular; but most of them are irregular in outline. The mineral originally occupying these positions in the rock was the least resistant one to weathering, and it was doubtless analcite. Two varieties of feldspar are present; the most abundant one is a polysynthetically twinned calcic plagioclase which occurs in small grains; the other is not twinned except occasionally on the Carlsbad law, and with its low index of refraction has been identified as orthoclase. The very much clouded condition of the ground-mass from alteration products frequently renders the absolute optical indentification of the feldspars impossible.

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[13] Professional Paper No. 14, U. S. Geological Survey, 1903, pp. 207–213.

Augite, which is the most abundant mineral in the rock, appears to be identical with that occurring in the camptonite, which is described in detail below. Hornblende was not identified in any of the thin-sections. Brown biotite is an abundant constituent, strongly pleochroic (x and $y =$ dark brown, $z =$ yellow), and occurs in hexagonal plates and irregular shreds. Apatite occurs in small prismatic crystals included in the principal minerals, but does not appear to be abundant.

The numerous light-

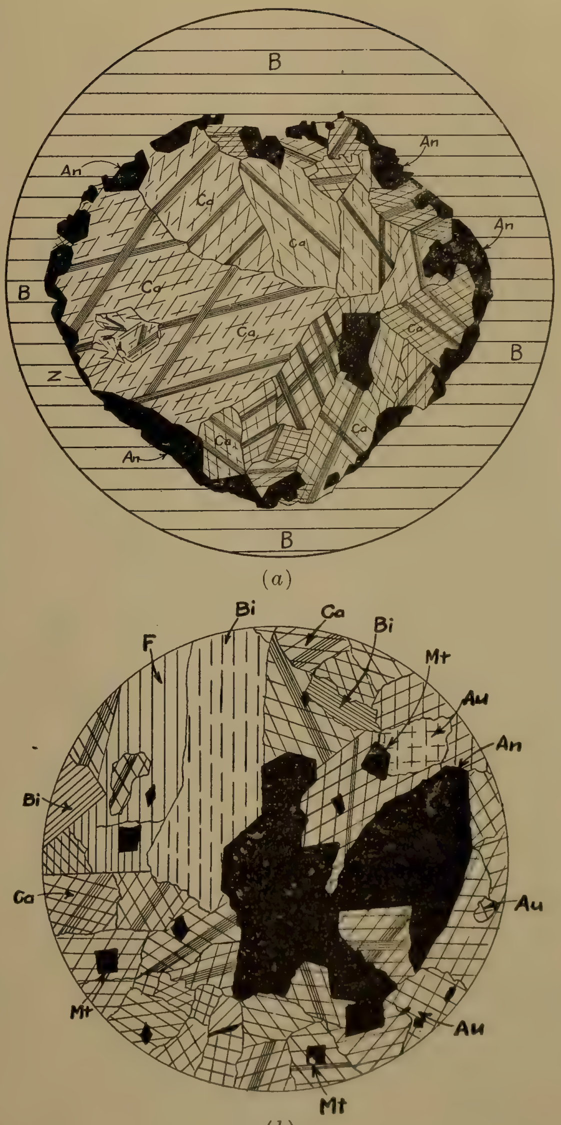

FIGURE 2.—*Microscopic Sketches of Thin-sections of Teschenite illustrating occurrence of Analcite*

(*a*) Phenocryst showing relations of analcite (*An*) to calcite (*Ca*) and ground-mass minerals (B). (Magnification, 32 diameters.) Note the well-developed crystal outlines of the analcite. The calcite is secondary, probably along with zeolite (Z) replacing analcite, which as an original constituent occupied the entire area.

(*b*) Shows analcite occupying interstices among the minerals of the ground-mass in the teschenite. (Magnification, 90 diameters.) The analcite has been partially replaced by calcite. Both (*a*) and (*b*) are typical of the occurrence of analcite in teschenite and camptonite.

colored areas (phenocrysts) in the rock are occupied by calcite, fibrous zeolites, and an isotropic mineral identified as analcite. Analcite usually occupies the outer part of the area and calcite the center, the latter always being in excess. Analcite also occurs as a constituent of the ground-mass and is the original mineral from which the calcite and fibrous zeolites of the light-colored areas (phenocrysts) have been derived. These relations are well shown in figure 2.

Chemical composition and classification in the quantitative system.—For the purpose of studying the chemical composition of this rock, the Glick Farm dike was selected as the freshest and most representative. In the table below is given the analysis of this rock by Mr. J. Wilbur Watson, and analyses of related rocks are added for comparison. As will be observed from the analysis (column I), the Virginia rock was not fresh, although it had the appearance of such in the hand specimen. Partial alteration of the rock is also shown in the microscopic study of thin-sections. One of the most abundant secondary minerals in the rock is calcite, as shown under the microscope and by the large percentage of CO_2 in the analysis.

Analyses of Teschenite (Analcite-basalt) and related Rocks

	I	II	III	IV	V	VI
SiO_2	40.40	46.77	39.64	41.10	48.35	47.82
Al_2O_3	13.49	14.91	16.98	14.82	13.27	13.56
Fe_2O_3	5.87	7.80	6.61	2.35	4.38	4.73
FeO	4.88	4.90	9.31	10.38	3.23	4.54
MgO	8.01	2.94	6.65	9.43	8.36	7.49
CaO	10.02	6.30	10.58	10.56	9.94	8.91
Na_2O	3.45	4.97	5.95	3.94	3.35	4.37
K_2O	2.94	2.37	3.09	1.28	3.01	3.23
H_2O-	0.61	0.92	1.32	0.39	0.90	3.37
H_2O+	3.06	4.28		2.31	2.89	
TiO_2	2.21	2.31	....	3.20	0.52	0.67
P_2O_5	1.09	0.98	....	0.19	0.40	1.10
MnO	0.63	0.29	....	0.14	0.19	Trace
BaO	....	0.04	....	0.06	0.54	0.16
CO_2	3.72	Trace	....	0.26	0.30	....
S	0.19	....	....	....	....	Trace
				Rest	0.34	0.25
	100.57	99.90	100.13	100.41	100.01	100.20

I. Teschenite (analcite-basalt) from dike on Glick farm, 4 miles east of Mount Solon, Augusta County, Virginia. J. Wilbur Watson, analyst.

II. Teschenite from Mapleton township, Aroostook County, Maine. W. F. Hillebrand, analyst. (Described by H. E. Gregory in Bulletin 165, U. S. Geological Survey, 1900, p. 183.)

III. Teschenite from Praya, Cape Verde Islands. F. Kertscher, analyst. (F. Eigel, Tschermaks Min. und Petrog. Mitteilungen, vol. xi, 1090, p. 98.)

IV. Analcite-basalt from Fernhill dike, Sydney, New South Wales. H. P. White, analyst. (Records of the Geological Survey, New South Wales, vol. 7, 1902, p. 93.)

V. Analcite-basalt from Big Baldy Mountain, Little Belt Mountains, Montana. W. F. Hillebrand, analyst. (L. V. Pirsson, Twentieth Annual Report of the U. S. Geological Survey, 1900, part iii, p. 548.)

VI. Monchiquite from Highwood Gap, Highwood Mountains, Montana. H. W. Foote, analyst. (L. V. Pirsson, Bulletin 148, U. S. Geological Survey, 1897, p. 153.)

The classification of this rock in the quantitative system is shown in the following computation of its norm and position:

Norm		
Or	17.24	47.09
Ab	3.14	
An	12.51	
Ne	14.20	
Ol	7.20	46.33
Di	23.24	
Mt	8.58	
Il	4.26	
Ap	2.69	
Pr	0.36	
H_2O	3.67	
CO_2	3.72	
	100.81	

Ratios

Class, $\frac{\text{Sal}}{\text{Fem}} = \frac{47.09}{46.33} = 1.0 =$ III, salfemane.

Order, $\frac{\text{L}}{\text{F}} = \frac{14.20}{32.89} = 0.43 = 6$, portugare.

Rang, $\frac{K_2O + Na_2O}{CaO} = \frac{87}{45} = 1.9 = 2$, monchiquase.

Subrang, $\frac{K_2O}{Na_2O} = \frac{31}{56} = 0.55 = 4$, monchiquose.

Symbol	Name
III. 6. 2. 4.	Monchiquose (?).

CAMPTONITE[*] *(OUROSE (?))*

Megascopic character.—The rock is dark steel gray to grayish-black and holocrystalline porphyritic in texture. The ground-mass varies in texture from fine-grained (granitoid) to dense aphanitic. Phenocrysts of black hornblende and augite, the former more abundant and of larger size, are fairly abundantly distributed through the rock. A conspicuous feature of the rock is the numerous large and small areas of white and pinkish (flesh) colors of more or less rounded outline, which are probably phenocrysts of light-colored minerals, although some of them bear a striking resemblance to amygdaloidal cavities. The microscopic evidence is not conclusive, but apparently favors the former view, that these areas are phenocrysts. The areas range in size up to 3 centimeters by 2 centimeters respectively.

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[*] A camptonite dike, not shown on the map, figure 1, occurs two miles north 80° east of Mount Sidney, Augusta County, which apparently represents a gradational type. In texture and kinds of minerals present, the rock does not differ from the normal camptonite described below, but the essential difference is in the relative abundance of light and dark colored minerals—the greater abundance of the former (feldspars) imparting a lighter color to the rock. Analcite is present in about the same amount, but the dark mafic minerals, hornblende, augite, and biotite, while occurring in the same manner as in the normal camptonite, are greatly exceeded in quantity by feldspar, both as phencrysts and in the ground-mass.

Plate 9, figure 2, is a view of a camptonite dike exposed along the public highway one mile north of Mossy Creek.

The general appearance of the hornblende and augite developed as phenocrysts is very similar, but they can generally be distinguished by the usual characteristic difference in form and the more or less altered condition of the augite, which is often surrounded by a border of secondary granular pyrite. Augite is frequently partially replaced by calcite from alteration, which can either be seen or detected by acid; also in the larger crystals of augite small scales of chlorite can sometimes be detected. A crystal removed from the matrix usually crumbles during the process into granules of altered minerals. Hornblende, on the other hand, appears fresh, and never shows in fresh specimens of the rock any indication of alteration; even on weathered surfaces of the rock it stands out in relief with brilliant luster and perfect crystal form.

The phenocrysts of hornblende, except the needle-like forms of the ground-mass, are mostly idiomorphic in outline, elongated in the direction of the *c* axis, and exhibit the usual faces 110, 010, 011, with sometimes 101 as small faces. The minute, needle-like forms in the ground-mass show the faces of the prismatic zone, but rarely the domes. The largest phenocryst of hornblende observed in the hand specimens was 2 centimeters in length and 5 millimeters in thickness. On removal from the matrix the crystal was broken open and found to contain a core of quartz about 1 centimeter in length. The center of this core was pure quartz, but as the margin was approached minute prisms of hornblende appeared, which became more abundant until the quartz entirely gave way to the hornblende substance of the surrounding crystal.

Microscopic character.—The essential minerals of the camptonite as seen in thin-sections under the microscope are hornblende, augite, feldspar (orthoclase and plagioclase), and analcite. Apatite, biotite, and magnetite occur in appreciable microscopic quantity, while titanite, rutile, and quartz are developed sporadically.

Hornblende is very abundant, developed in large, well-formed crystals and in small microliths scattered through the rock-mass. It is highly pleochroic; $x =$ light brown, $y =$ pale yellowish-brown, and $z =$ deep brown. The inclination of c to z is about 20° and the variety of amphibole is common basaltic hornblende, which is confirmed by the subjoined chemical analysis.

Chemical Analysis of Hornblende from Camptonite

(J. G. Dinwiddie, analyst)

SiO_2	39.65
Al_2O_3	13.61
Fe_2O_3	3.96
FeO	10.58
MgO	11.36
CaO	11.16
Na_2O	1.99
K_2O	2.19
H_2O	1.43
TiO_2	5.01
MnO	0.06
	101.00

As will be observed, the ferrous iron and soda in this analysis are too low for arfvedsonite or barkevikite. The hornblende is zonally built, as shown in figure 4. It is usually quite fresh, but where alteration occurs, pale green chlorite and magnetite are noted as the secondary products. Twinning is common, the composition plane being in most cases 100. Sometimes several lamellæ occur in the same individual. Figure 3 shows a case of abnormal twinning.

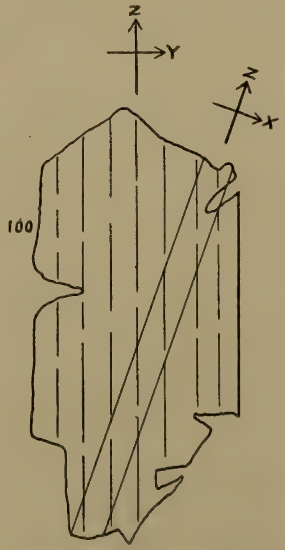

Figure 3.—*Sketch showing abnormal Twinning in Hornblende of Camptonite*

Augite is developed as an important constituent in all the thin-sections studied, but is much less abundant than hornblende. It occurs in short, stout, well formed crystals, with the faces 100, 110, 010, and often 011, and in crystal aggregates. It is almost colorless except in the border zones, which are sometimes grass green. The inclination of c to z is about 44°. Zonary growth is common (figure 4), the colorless augite of the central zone of some crystals passing into an outer zone of grass green ægirite, while in others the entire crystal is colorless and the zones can be detected only by differences in optical orientation. In the latter case the outer zone sometimes shows an extinction angle 2 to 3 degrees larger than that of the inner zone. In some crystals, where there are numerous concentric zones, a wave of extinction passes from the center to the margin of the crystal. In other cases extinction starts midway between the center and margin and moves in opposite directions from the inner zone toward the center and from the outer zone toward the margin. Twinning is common parallel to 100. The augite is rarely as fresh as the hornblende, and more or less alteration is noted in all individuals to chlorite, calcite, and pyrite, which takes place first around the margin and along cleavage lines and cracks.

The absolute identification of the feldspars is attended with difficulty because of their altered condition. In some parts of the thin-sections microcline appears to be the chief feldspar and in others orthoclase or andesine-labradorite. Microcline is developed in grains and in irregular masses sometimes of large size and showing the characteristic microcline structure and Carlsbad twinning. Orthoclase is likewise fairly abundant in some parts of the thin-sections. Its occurrence and distribution are similar to microcline, but it is probably not so abundant and on the whole does not occur in as large individuals. The plagioclase is developed chiefly in prismatic forms showing characteristic multiple twinning and large extinction angles. It is of the calcic variety and corresponds in composition to andesine-labradorite.

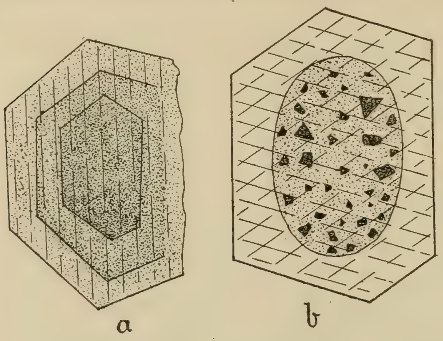

FIGURE 4.—*Sketches illustrating zonal Structure observed in Hornblende of the Camptonite.*

(*a*) Hornblende idiomorph showing zonal bands with crystal outlines. (*b*) Hornblende idiomorph showing ellipsoidal zonal structure.

Analcite occurs in all thin-sections studied, but not evenly distributed. Its prevailing mode of occurrence is in the form of phenocrysts, which are abundant in the coarser-grained rock. It is also developed in small grains occupying the interstices between the feldspars and mafic silicate minerals of the ground-mass. These phenocrysts as seen under the microscope are composed either of a single individual, with or without crystal form, or of a group of idiomorphic individuals, some of which have been replaced by calcite and fibrous zeolites through alteration. In some cases where the area is occupied by a single individual it shows idiomorphic outline and sharp contacts with the surrounding minerals. In other instances no crystal boundaries occur, but the analcite, although pure in the central zone, passes outward into the interstices between the minerals of the ground-mass. Where a phenocryst is made up of a number of individuals, the contact with the ground-mass is usually quite sharp, with the analcite crystals in the border zone occurring as partial idiomorphic individuals with crystal faces on the inner border, although in some instances complete forms occur (see figure 2).

The analcite is sometimes faintly doubly refracting in parts of the individual. Distinct traces of cubic cleavage sometimes occur. Replacement of analcite by calcite and fibrous zeolitic material is commonly observed, and in many instances only a small percentage of the analcite remains. In some cases the alteration has progressed first from the inner zone, in others from the outer zone, and sometimes from both. That the analcite is a pyrogenetic constituent of the rock is practically certain. Its occurrence indicates that two periods of crystallization are represented, the first that of material which had segregated in the magma resulting in the formation of a single individual or a group of individuals, and a second of a later period developing the irregular grains in the ground-mass.

Biotite occurs in minor quantity as small individuals which sometimes show crystal form. Basal sections are dark reddish brown. Sections normal to the cleavage are pleochroic, ranging from very dark brown to light yellow. It is usually fresh, but sometimes shows alteration to chlorite.

Magnetite, titanite, rutile, apatite, and quartz occur as original minor accessory constituents. Magnetite is abundant as inclusions in the younger minerals and is usually idiomorphic in outline. Titanite is developed in small anhedra, with sometimes minute inclusions of rutile crystals, but is not abundant. Apatite as small euhedral and rounded forms occurs as included crystals in the other minerals and as separate larger idiomorphic crystals, measuring up to 0.5 millimeter in diameter among the minerals of the ground-mass. Quartz does not occur among the minerals of the ground-mass, but only within the hornblende, where it is developed as small inclusions of microscopic size and larger masses as the core of a hornblende crystal, constituting as much as 25 per cent of its volume.

The secondary minerals are zeolites, biotite, chlorite, calcite, pyrite, and a small amount of epidote. The zeolites occupy areas within the altered portions of the analcite and plagioclase feldspar. Biotite occurs in small flakes and is associated with the zeolites and epidote. Calcite occurs in the same manner as a replacement of the various lime-bearing minerals in the thin-sections. Chlorite is most abundant in areas occupied originally by augite, and it also occurs as an alteration product of biotite and to a small extent of hornblende. Pyrite is found associated with chlorite, magnetite, and calcite in partially altered augite.

Chemical composition and classification in the quantitative system. The composition of this rock is shown in the chemical analysis given in column I of the subjoined table, and there are added for comparison analyses of three related rocks in columns II, III, and IV. It will be seen that the rocks have in general similar features of chemical composition, and, as shown below, except II, they have the same position in the quantitative system and are designated by the same subrang name, *ourose.*

Analyses of Camptonite and related Rocks

	I	I*a*	II	III	IV
SiO_2	43.26	.721	41.94	43.74	42.46
Al_2O_3	14.01	.137	15.36	14.82	12.04
Fe_2O_3	7.17	.045	3.27	2.40	2.19
FeO	5.41	.075	9.89	7.52	5.34
MgO	5.57	.139	5.01	6.98	12.40
CaO	10.09	.180	9.47	10.81	12.14
Na_2O	2.83	.045	5.15	3.08	1.21
K_2O	3.78	.040	0.19	2.90	2.68
H_2O-	0.49	....	3.29	2.94	4.03
H_2O+	2.74	....			
TiO_2	1.81	.023	4.15	2.80	2.47
P_2O_5	1.18	.008	....	0.64	0.84
MnO	0.34	.005	0.25	....	0.16
S	0.21	.006	....	0.10	....
CO_2	1.57	....	2.47	1.50	0.55
	100.46		100.44	100.23	99.51

I. Camptonite (analcite-hornblende-basalt) from Mossy Creek, Augusta County, Virginia. J. Wilbur Watson, analyst.

I*a*. Molecular ratios from I.

II. Camptonite from Campton Falls, New Hampshire. G. W. Hawes, analyst.

III. Monchiquite, Rio do Ouro, Serra de Tingua, Brazil. Hunter and Rosenbusch, Tschermak's Min. und Petrog. Mitth., vol. xi, 1890, p. 464.

IV. Monchiquite, Willow Creek, Castle Mountains, Montana. Weed and Pirsson, Bulletin 139, U. S. Geological Survey, 1896, p. 115.

The position of the rock in the quantitative system is indicated in the following computed norm and ratios, which show it to be *ourose:*

Norm		
Or	22.24	53.08
Ab	7.86	
An	14.46	
Ne	8.52	
Ol	3.38	42.38
Di	22.01	
Mt	10.44	
Il	3.50	
Ap	2.69	
Pr	0.36	
H_2O	3.23	
CO_2	1.57	
	100.26	

Ratios

$$\text{Class, } \frac{\text{Sal}}{\text{Fem}} = \frac{53.08}{42.38} = 1.2 = \text{III, salfemane.}$$

$$\text{Order, } \frac{\text{L}}{\text{F}} = \frac{8.52}{44.56} = 0.19 = 6\text{, portugare.}$$

$$\text{Rang, } \frac{K_2O + Na_2O}{CaO} = \frac{85}{52} = 1.63 = 3(2)\text{, limburgase-monchiquase}$$

$$\text{Subrang, } \frac{K_2O}{Na_2O} = \frac{40}{45} = 0.9 = 3\text{, ourose.}$$

Symbol	Name
III. 6. 3(2). 3.	Ourose (?).

Only two representatives of the sodipotassic subrang ourose of the rang limburgase are listed in Washington's[14] tables. Both of these are described as monchiquite; one (column IV), by Weed and Pirsson, from Willow Creek, Castle Mountains, Montana; the other (column III), by Hunter and Rosenbusch, from Rio do Ouro, Serra de Tingua, Brazil.

OLIVINE DIABASE (AUVERGNOSE)

Megascopic character.—Of the five types of igneous rocks thus far identified in this region, diabase including basalt, is much the most frequent and abundant in occurrence. Careful study of the rock in its numerous field occurrences and in thin-sections under the microscope reveals remarkable uniformity without trace of unusual feature in any one of the many exposures examined. In every respect—general physical appearance, texture, and mineral composition—the rock is identical with the normal Triassic diabase of the Piedmont province.

Naturally, some variation in the size of grain is observed in different dikes and in different parts of the same dike in the larger ones, the range in granularity being from medium to fine grained (aphanitic). Rarely are any of the minerals in the coarser grained specimens sufficiently large to be termed phenocrysts, yet in hand specimens it can usually be seen that the rock is composed of both dark and light colored minerals. The fresh rock is dark bluish gray in color, but those specimens in which olivine is abundant the rock usually has a greenish cast.

Microscopic character.—Thin-sections of all the field occurrences of diabase noted by the writers were studied microscopically and were found to be remarkably uniform in texture and composition, without variations from the normal type of the Triassic olivine diabase. Without exception the texture is typically diabasic or ophitic, the lath-shaped crystals of plagioclase measuring in some cases as much as 3 millimeters in length, but the average is probably less than half of this. From a microscopic study of specimens of basalt collected by Darton from the dikes in Highland County, Virginia, Keith[15] states that there are three distinct types of texture—basaltic, diabasic, and porphyritic. In 1889 Diller[16] examined microscopically four specimens of similar rocks collected by Darton from the same county and remarked that "all are of the holocrystalline porphyritic type of basalt."

In mineral composition the rock is an olivine diabase, although the amount of olivine present is subject to considerable variation. In most of the thin-sections studied olivine is abundant, but in a few it is developed only in small quantity. This is in accord with the microscopic examination of specimens of similar rocks from the Highland County area by Diller and Keith. In addition to olivine, the other primary minerals named in the order of abundance are plagioclase, augite, magnetite, a little orthoclase, and apatite as inclusions in the feldspars. Usually these minerals are quite fresh, but some alteration is noted, yielding the secondary minerals serpentine, chlorite, calcite, kaolin, quartz, amphibole, and magnetite.

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[14] Professional Paper No. 14, U. S. Geological Survey, 1903, pp. 342-343.

[15] Amer. Jour. Sci., 1898, vol. vi, p. 314.

[16] Ibid., 1890, vol. xxxix, p. 270.

Plagioclase is developed in lath-shaped crystals up to 3 millimeters in length and is of the calcic variety, corresponding to labradorite-bytownite in composition. Orthoclase is usually present in minute quantity formed in the interstices between the plagioclase and other minerals. Augite occurs in irregular grains, nearly colorless to very pale brown, and as a rule does not exhibit noticeable pleochroism. Like the feldspar, it often shows wavy extinction due possibly to dynamic strain. Most of the augite is quite fresh, but some alteration is observed, yielding chlorite, calcite, sometimes a little hornblende in small prismatic needles, and magnetite. Olivine occurs chiefly in grains, whose outlines occasionally suggest crystal form. Its period of crystallization was contemporaneous with but near the close of that of plagioclase, while the period of formation of augite was later. The fresh olivine is nearly colorless and the size of grain ranges up to 3 millimeters. It usually shows some alteration, which has progressed in the usual way along cleavage and fracture directions and about the borders. In a few cases the entire grain is altered, but as a rule the alteration is only partial, the products being green fibrous serpentine, calcite, and minute grains and crystals of magnetite.

Magnetite as an original constituent occurs as crystals in all the thin-sections, but in no case is it abundant. Apatite is developed only as minute inclusions chiefly in the plagioclase feldspar.

Chemical composition and classification in the quantitative system.—The chemical composition of the olivine diabase is well shown in the analysis of the rock from a representative dike at Cross Keys, Augusta County, given in column I of the subjoined table. The analysis of a Piedmont olivine diabase from Davidson County, North Carolina, is added for comparison in column II.

Analyses of Olivine Diabase

	I	*Ia*	II
SiO_2	48.10	.802	47.66
Al_2O_3	15.25	.150	19.24
Fe_2O_3	2.57	.016	1.83

	I	I*a*	II
FeO	8.28	.115	8.67
MgO	9.33	.233	10.79
CaO	11.11	.198	9.91
Na_2O	1.48	.024	1.14
K_2O	0.35	.006	0.26
H_2O-	0.53	....	0.06
H_2O+	1.22	....	
TiO_2	0.69	.009	....
MnO	0.15	.003	....
P_2O_5	0.11	.001	....
CO_2	0.83	....	....
S	0.20	.006	....
	100.20		99.56

I. Chemical analysis of olivine diabase from Cross Keys, Augusta County, Virginia. J. Wilbur Watson, analyst.

I*a*. Molecular ratios calculated from I.

II. Chemical analysis of olivine diabase from near Fairmont, Davidson County, North Carolina. A. S. Wheeler, analyst. (Described by J. E. Pogue in Proceedings of the U. S. National Museum, vol. 37, 1910, pp. 475-484.)

The norm as calculated from the chemical analysis given in column I of the table above and the position of the rock in the quantitative system are expressed as follows:

Norm		
Or	3.34	49.28
Ab	12.58	
An	33.36	
Ol	2.53	48.70
Di	16.90	
Hy	23.49	
Mt	3.71	
Il	1.37	
Ap	0.34	
Pr	0.36	
H_2O	1.75	
CO_2	0.83	
	100.56	

Ratios

Class, $\frac{\text{Sal}}{\text{Fem}} = \frac{49.28}{48.70} = 1.01 =$ III, salfemane.

Order, $\frac{Q}{F} = \frac{0}{49.28} = 0 = 5$, gallare.

Rang, $\frac{K_2O + Na_2O}{CaO} = \frac{30}{120} = 0.25 = 4$, auvergnase.

Subrang, $\frac{K_2O}{Na_2O} = \frac{6}{24} = 0.25 = 4\text{-}5$, auvergnose.

Symbol	Name
III. 5. 4. 4-5.	Auvergnose.

Summary and Conclusions of the Petrologic Relations of the Rock Types

INTRODUCTION

The distribution and geologic occurrence and the petrography of the rocks having been described in some detail, it remains to summarize the general petrologic relations of the rock types to each other. These relations (regional characters) are briefly summarized under (*a*) chemical, (*b*) mineralogical, and (*c*) textural characters.

The rocks of the region are naturally grouped into two principal subdivisions: (1) Those in which the felsic constituents are dominant, including felsophyre, quartz gabbro (norite), and nepheline syenite; and (2) those in which the mafic constituents are dominant, including diabase and basalt, teschenite, and camptonite. The rocks show certain evidences of kinship in chemical and mineralogical composition, and to a less extent in texture, which mark them as differentiates from a common or parent magma, and are interpreted broadly as representing a group or series of complementary dikes. This relation does not admit of reasonable doubt for the closely parallel series of nepheline syenite, quartz gabbro, teschenite, and camptonite dikes found in the northern part of Augusta County, 4 miles southwest from Bridgewater (see map, figure 1, and figure 5). Figure 5 illustrates most strikingly this relation.

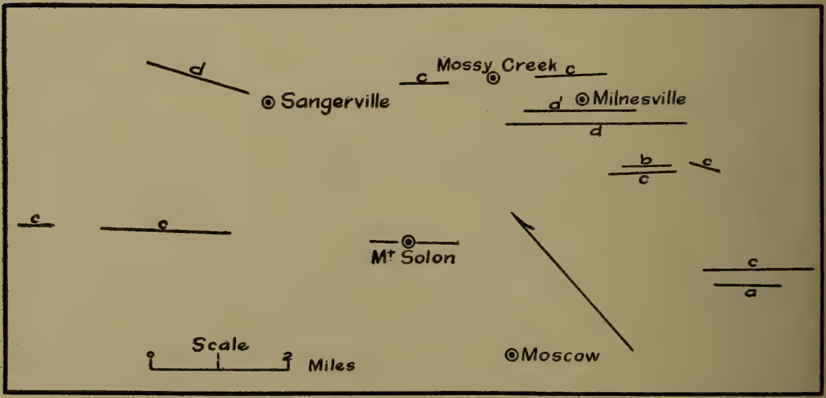

FIGURE 5.—*Diagram illustrating kinship Relations of Dikes in northern Augusta County, Virginia, on the Basis of relative Distribution*

(*a′*) Nepheline syenite containing biotite, a little hornblende and augite as mafic minerals, intimately associated with (*d*) teschenite containing the same mafic minerals; (*a*) nepheline syenite containing hornblende as principal mafic mineral associated with (*c*) camptonite in which hornblende is the similar dominant mineral; (*b*) quartz gabbro (norite). The powder of each of these rocks, except (*b*) quartz gabbro, when boiled with hydrochloric acid, filtered and evaporated, yields copious gelatinous silica.

CHEMICAL CHARACTERS

The chief chemical characters of the rocks of the region as developed from the table of analyses below may be summarized as follows: Silica with one exception (I) is generally low and deficient. Alumina is fairly uniform except in II and III (nepheline syenites, miaskose), where it averages roughly 20 per cent and is appreciably higher than in the other analyses. Iron oxides and magnesia are low in I, III, and IV, but are correspondingly high in the other four (II, V, VI, and VII), with a similar variation noted in lime, a difference which results from the distribution in amount of mafic silicate minerals in the two groups of rocks. Ferrous iron and magnesia combined dominate total lime, being approximately equal in several cases. The total alkalies are usually high, with the range in soda from low to very high, and potash generally high, but very low in IV. Soda without exception molecularly exceeds potash.

Chemical Analyses of igneous Dike Rocks from Middle Western Virginia

	I	II	III	IV	V	VI	VII
SiO_2	69.56	57.62	54.77	53.57	48.10	43.26	40.40
	1.159	.960	.912	.892	.802	.721	.673
Al^2O^3..............	15.52	16.44	21.41	22.46	15.25	14.01	13.49
	.152	.161	.210	.221	.150	.137	.132
Fe^2O^3..............	1.67	2.34	2.46	1.01	2.57	7.17	5.87
	.011	.014	.016	.006	.016	.045	.037
FeO	1.19	4.89	0.68	0.92	8.28	5.41	4.88
	.017	.068	.010	.013	.115	.075	.068
MgO	0.41	2.53	0.18	0.37	9.33	5.57	8.01
	.010	.064	.004	.009	.233	.139	.200
CaO	1.20	6.40	0.47	1.49	11.11	10.09	10.02
	.021	.114	.009	.027	.198	.180	.179
Na_2O	4.46	2.91	9.53	10.22	1.48	2.83	3.45
	.073	.047	.153	.165	.024	.045	.056
K_2O	4.68	1.52	4.97	5.14	0.35	3.78	2.94
	.050	.016	.053	.054	.006	.040	.031
H_2O-	0.34	0.20	0.17	0.43	0.53	0.49	0.61
H_2O+	0.67	1.15	4.61	2.97	1.22	2.74	3.06
TiO_2	0.31	0.64	0.08	0.20	0.69	1.81	2.21
	.004	.008	.001	.003	.009	.023	.028
P_2O_5	0.08	0.29	0.07	0.11	0.11	1.18	1.09
	.001	.002	.001	.001	.001	.008	.008
MnO	0.07	0.27	0.68	0.56	0.15	0.34	0.63
	.001	.004	.010	.008	.003	.005	.008
BaO..............	0.10	....	....	....	....	....	....
	.001	....	....	....	....	....	....
CO_2	None	3.75	0.03	0.95	0.83	1.57	3.72
				.020	.018	.036	.084
S	Trace	None	....	0.17	0.20	0.21	0.19
				.006	.006	.006	.006
	100.26	100.95	100.11	100.57	100.20	100.46	100.57

I. Felsophyre from Monterey Mountain, Highland County, Virginia. W. F. Hillebrand, analyst.

II. Quartz gabbro from Arey farm, 1.5 miles south of Milnesville, Augusta County, Virginia. J. G. Dinwiddie, analyst.

III. Nepheline syenite from Glick farm, 4 miles east of Mount Solon, Augusta County, Virginia. J. Wilbur Watson, analyst.

IV. Nepheline syenite from property adjoining the Charles Curry farm, 5 miles southeast of Mount Solon, Augusta County, Virginia. J. G. Dinwiddie, analyst.

V. Olivine diabase from Cross Keys, Augusta County, Virginia. J. Wilbur Watson, analyst.

VI. Camptonite (analcite-hornblende-basalt) from Mossy Creek, Augusta County, Virginia. J. Wilbur Watson, analyst.

VII. Teschenite (analcite-basalt) from Glick farm, 4 miles east of Mount Solon, Augusta County, Virginia. J. Wilbur Watson, analyst.

In the annexed table are tabulated the norms of the rocks, arranged in the same order as the analyses in the table above. Further chemical relations are developed from a study of this table, especially the relations of the rocks in the quantitative system of classification.

Table of Norms

	I	II	III	IV	V	VI	VII
Q	22.50	15.78	....	....	....	....	....
Or	27.80	8.90	29.47	30.02	3.34	22.24	17.24
Ab	37.73	24.63	35.63	25.68	12.58	7.86	3.14
An	5.28	27.24	1.11	0.56	33.36	14.46	12.51
Ne	....	....	24.14	32.94	....	8.52	14.20
C	1.12	....	....	....	....	....	....
Hy	1.53	11.97	....	....	23.49	....	....
Di	....	2.07	0.46	4.18	16.90	22.01	23.24
Ol	....	....	0.41	....	2.53	3.38	7.20
Wo	....	....	....	0.46	....	....	....
Mt	2.32	3.25	3.71	1.39	3.71	10.44	8.58
Il	0.61	1.22	0.15	0.46	1.37	3.50	4.26
Ap	0.34	0.67	0.34	0.34	0.34	2.69	2.69
Pr	....	....	....	0.34	0.36	0.36	0.36
Rest	1.01	5.10	4.81	4.35	2.58	4.80	7.39
	100.24	100.83	100.23	100.72	100.56	100.26	100.81

Quartz is noted in only two of the seven norms, toscanose (I) and tonalose (II). The feldspars are present in large amount in all the norms, the individual species showing wide range, with orthoclase and albite usually in largest percentages. Anorthite is very subordinate in amount in the persalanes (I, III, and IV), but is one of the dominant species in dosalane (II) and in the salfemanes (except in ourose). The lenad, nephelite, ranging in amount from 8.5 to 33 per cent, is present in four of the seven norms.

The femic minerals are practically negligible in the three persalanes (I, III, and IV), but are present in large amounts in dosalane (II) and in the three salfemanes (V, VI, and VII). Olivine and diopside are present in each of the salfemanes, but vary within rather wide limits. Magnetite, ilmenite, and apatite, the magnetite always dominant, are present in each norm in small amounts in the persalanes, but more abundant in the salfemanes.

MINERALOGICAL CHARACTERS

No single mineral as an essential constituent of the rocks occurs in all types recognized in the region, but several are present in widely different amounts in all the rocks, varying as to the relation of felsic and mafic constituents.

Quartz actually occurs as a constituent in only two of the rock types, the persalane toscanose and the dosalane tonalose, the general character of the magmas representing the other types being such as to preclude its presence. The feldspars, orthoclase and plagioclase, may be regarded as persistent minerals, since they form large but varying percentages in all the rocks. Orthoclase is developed as an essential component of each type except the salfemane, auvergnose, in which it is noted only as a very minor accessory. Plagioclase, in large but varying percentages, ranges from the sodic variety, albite, in toscanose to the sodic-calcic varieties in the six remaining types. Nephelite and analcite are developed as principal components of miaskose, monchiquose, and ourose, the former being limited to miaskose and the latter to monchiquose and ourose.

Of the mafic minerals biotite is perhaps the most persistent, being a component of all types, but is only of quantitative importance in monchiquose and ourose. Augite is present in large amount in dosalane (II) and in the salfemanes (V, VI, and VII), and is sparingly developed in the persalanes (I, III, and IV). Hornblende is essentially absent from the rocks of the entire region, except in the closely related group of dikes (miaskose, monchiquose, and ourose) in the northern part of Augusta County, where it is most abundant in monchiquose and is developed only as a minor constituent of miaskose and ourose. Olivine as a modal mineral is limited exclusively to auvergnose, it being present in every specimen of this type studied.

The lesser minerals, developed only as microscopic accessories, exercise no important influence on the character of the rocks and need not be discussed.

TEXTURAL CHARACTERS

The rocks of the region are all intrusive, occurring without exception as dikes; are holocrystalline, and range in granularity from medium coarse to fine and dense aphanitic. They are characterized by a variety of texture—porphyritic, diabasic, and even granular—the latter ranging from medium-grained in some of the nephelite syenite to dense aphanitic in the basalts. With the exception of the diabase, each rock type may show porphyritic texture. In the granite-felsophyre and nephelite syenite the phenocrysts are composed chiefly of the felsic constituents, orthoclase and albite in granite-felsophyre, and orthoclase in nepheline syenite. Scant development of mafic minerals is also observed, a little biotite and augite in granite-felsophyre, and a few plates of biotite with an occasional crystal of hornblende in nepheline syenite. In the basic types (teschenite, camptonite, and basalt) the phenocrysts are dominantly mafic minerals, including hornblende, augite, olivine, and less biotite. In addition to the mafic minerals, analcite is frequently developed as phenocrysts in the teschenite and camptonite.

Age Relations of the igneous Rocks

Because of the relationship of the dikes of the middle western district of Virginia, they are all regarded to be of the same age. Since they are found cutting the latest sedimentary rocks of the region, Mississippian, the dikes must be post-Mississippian in age. Furthermore, since the dikes show no evidence of having been subjected to the folding and faulting of the Appalachian revolution, they are post-Paleozoic. On the basis of distribution and structural relations, they appear, in light of our present knowledge, to be Triassic, as has been pointed out in another section of this paper. On the basis of lithologic character the diabases alone afford any evidence. In this respect they are identical with the diabase found in the numerous Triassic areas of the eastern United States. In view of these facts, the writers regard the dikes of central western Virginia to be of Triassic age.

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NORTHUMBERLAND VOLCANIC PLUG[1]

BY H. P. CUSHING

(Read before the Society December 28, 1912)

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LOCATION

A knob of volcanic or effusive rock of quite exceptional occurrence and character is found in Saratoga County, New York. It stands close to the west bank of the Hudson River, one mile north of the village of Schuylerville and 10 miles east of Saratoga Springs. Seen from the east, it appears as a knob some 70 feet in height on the margin of the terrace which fronts the river. Viewed from the west, it is much less prominent, standing only about 30 feet above the general level of the terrace. The terrace steadily rises in level to the west and soon exceeds the altitude of the knob's summit.

HISTORICAL

The knob is located well to one side of ordinary routes of travel and wholly escaped the attention of geologists until discovered, studied, and described by Woodworth in 1901.[2] It subsequently remained unvisited until studied by Ruedemann and myself in 1910 while engaged in preliminary study of the geology of the Schuylerville quadrangle. Between the two dates a considerable part of the knob had been quarried away for road metal and other purposes, exposing to view many structural features which were entirely hidden before quarrying began, and also furnishing comparatively fresh rock for microscopic and chemical study, in contrast to the badly altered surface material which only was available in 1901.

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[1] Manuscript received by the Secretary of the Society, April 21, 1913.
[2] 21st Rept. New York State Geology, pp. r17-24.

Woodworth proposed calling the hill "Starks Knob," and the name is a convenient one. The occurrence well merits description, since it is unusual and puzzling, quite unlike any other known occurrence of igneous rocks in New York, and because it is of importance to determine whether it has any significance in connection with the existence of the mineral waters of the Saratoga region.

Description

Woodworth had to depend on weathered surface materials in making his study; but since certain features of the rock were brought out by weathering and were better exhibited at that time than is the case today, we can not begin description of the occurrence in better fashion than by citations from his paper:

> "Starks Knob igneous mass lies surrounded on the ground by Hudson River slates.[3] These slates are highly inclined, cleaved and much broken rocks. . . . So far as my own observations go, there are no dikes radiating from the main mass into the sedimentary rocks, nor any noticeable sign of metamorphism in them attributable to the heating action of the lavas of the plug. . . . This lack of contact metamorphism and the failure of dikes are points of little value in determining the origin of the igneous rock. It remains to determine by other evidences whether it is intrusive or extrusive.
>
> "The igneous mass appears to be the superficial portion of a body which extends downward into the slates and, from its general form and surroundings, strongly suggests a neck or plug rising up through the Hudson River group at this point. The manner in which the slate body dips beneath the igneous mass on the northeast appears to indicate that the plug does not extend vertically downward through the slates, but follows guiding planes of structure.
>
> "The exposed faces of the rock of the knob exhibit cross-sections of ball and pear-shaped masses embedded in a base having a shaly structure. . . . Where the shaly, fine-grained base has peeled away the surface resembles the coarse, bulging surface of basalt streams, such as are seen in Hawaii. The whole has the appearance of a mass of bombs or lava balls, inclosing scoriaceous lava, or foreign inclusions embedded in a basaltic glass which is scaling to pieces along lines of flowage. A more probable explanation of the structure

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[3] These slates are chiefly of Normanskill age.

is that this mass represents a volcanic throat or plug at some depth below the actual crater, but not below the point to which explosive products may have fallen back into the volcano, there to become embedded in the still hot lava. Certainly the gross structure of the rock recalls many lava sheets with locally formed explosive products, and the same structure is to be observed in the lava flows of the Newark series in the Connecticut Valley."

Since Woodworth's study of the knob the rock has been utilized for various purposes and much of it quarried away. We visited it in 1910, in 1911, and in 1912. In 1910 active quarrying was in progress. In 1911 no work was being done, but much material had been removed since the previous visit. Between this and the summer of 1912 yet more was taken away, and now no great amount of the igneous rock remains above the general ground surface. Other geologists have also accompanied us to the spot—Van Ingen and Smyth in 1910, Kemp in 1911, and Woodworth in 1912.

Constitution of the Knob

GENERAL CHARACTER OF THE CONSTITUENT MATERIAL

The knob consists of lava balls, large and small, with intervening matter. The balls range up to 2 feet in diameter and perhaps average 1 foot. At the time of our first visit many of them lay about, being broken up by the quarrymen. They consist of dense, dull, black lava, so finely crystalline that crystals are neither visible to the eye nor to the hand lens.

The intervening matter has been badly ground and crushed, so that most of it has the aspect of slickensided, shaly material. The less crushed portions are always of glassy texture, consisting of black pitchstone. Both balls and pitchstone are locally amygdaloidal, but the amygdules are small and scattered. They are chiefly filled with calcite, as are also the cracks, which everywhere ramify through the rock.

INCLUSIONS

Inclusions abound throughout the knob. Though it stands surrounded by black shales, there are no inclusions of shale in it. All seen are of limestone, and limestone of but a single type, which effervesces immediately and briskly with acid and contains little or no magnesia. They range in size up to pieces a foot or more in diameter. Those in the pitchstone are often much corroded by the lava. In the balls corrosive action is much less prominent.

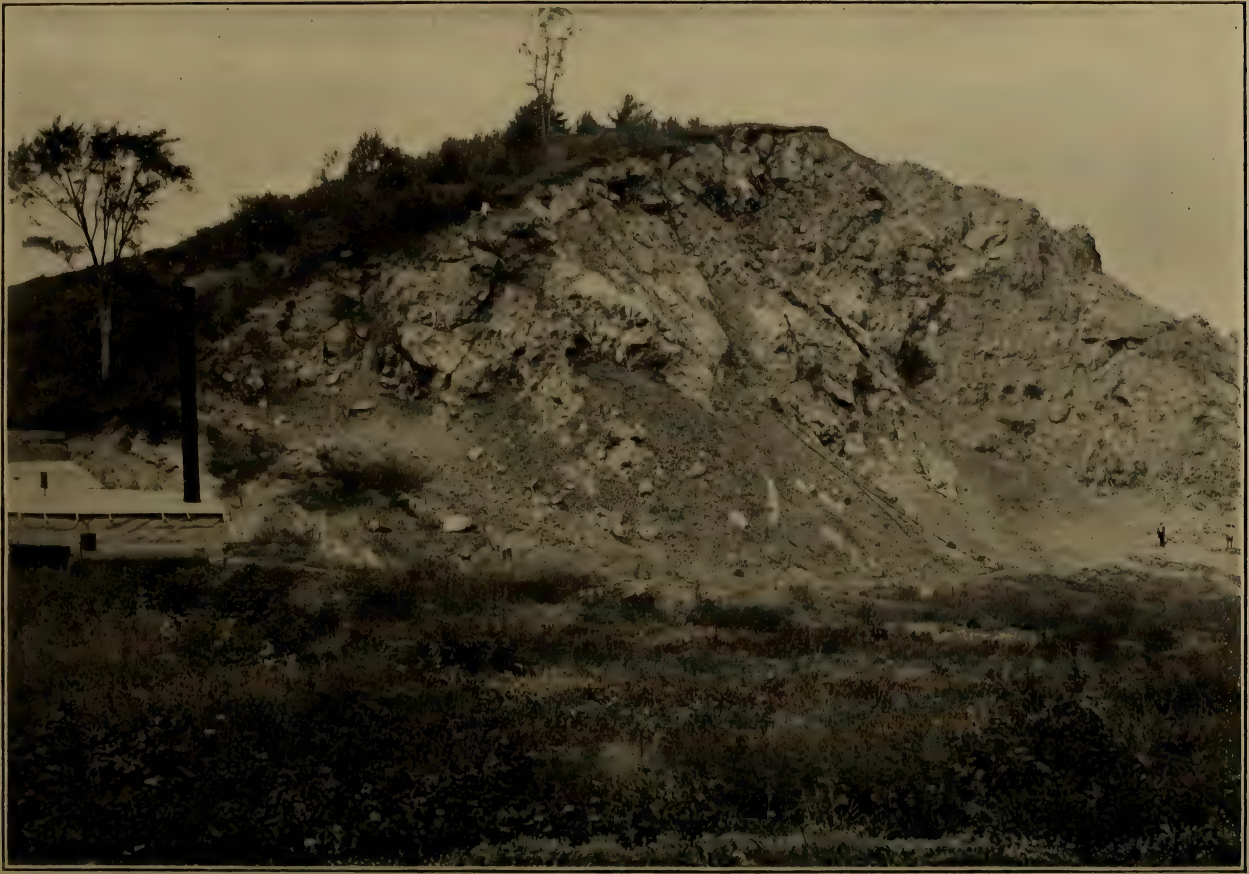
Whence came this limestone, from what formation of the region, and why are there no inclusions of other rocks, more especially of shale? This can not be discussed intelligibly without a brief consideration of the rock formations of the neighborhood.

THE SECTION

In the region in which the knob stands are two sharply contrasted sets of early Paleozoic formations, apparently deposits of two separate troughs, the one indigenous to the district and the other overthrust into it from the east. The knob stands within the eastern overthrust set of formations and the boundary between the two lies some five miles west of it. The western set are comparatively undisturbed and consist of the ordinary formations of the Champlain trough (Chazy basin), though the representation of these is very imperfect. The entire Beekmantown and Chazy groups and most of the Black River are not found in the section which comprises, in ascending order, the Potsdam sandstone and Little Falls dolomite of Upper Cambrian (Ozarkian) age, the Amsterdam limestone of Upper Black River age, and the Canajoharie shale of Trenton age.

The eastern set of formations are the Lower Cambrian (Georgian), in great thickness; the Dictyonema (Schaghticoke) shale, of extreme Upper Cambrian or lowermost Ordovician age; the Deepkill shale, of Beekmantown age; the Bald Mountain limestone, also of Beekmantown age, and the Normanskill and Snake Hill shales, of Chazy or Black River and of Trenton age. They are greatly disturbed and have been overthrust in sections, so that the upper shales reach farthest west; the Bald Mountain limestone has been overthrust on them, and the Georgian overthrust on the Bald Mountain. These overthrust beds thin out to disappearance to the west and must rest on the deposits of the Chazy basin. Therefore it would be possible for the limestone inclusions in the knob to have come from either set of formations. At the knob Normanskill shales are the surface rocks. Quite likely these rest on Bald Mountain limestone, followed beneath by the Canajoharie shale, Amsterdam limestone, Little Falls dolomite, and so on—the regular succession of the rocks of the Chazy basin.

Now, unless some formation occurs here underground which does not outcrop at the surface, some representative of the Beekmantown or Chazy formations of the usual Champlain section, the only formation of the district which could possibly have furnished such inclusions is the Bald Mountain limestone. The only limestone in the formations of the Chazy basin is the Amsterdam, which is thin and lies directly above the great thickness of Little Falls dolomite. It is unthinkable that igneous rock, rising through this series of formations, could have brought up such an abundance of fragments from the Amsterdam and not one from the great



STARKS KNOB, IN AUGUST, 1910, FROM THE SOUTHEAST

Showing the general form and relief. A comparison of plate 6 of Woodworth's paper will indicate the amount of excavation dolomite just beneath. The question of the source of the inclusions becomes of importance in the discussion of another problem and will be reverted to presently.

The knob is surrounded by black shales, chiefly Normanskill, and it would seem as if the lava must have risen through a large thickness of such shale lying above the limestone. There are also frequent bands of very resistant grit in these shales. Under the circumstances the utter lack of recognizable inclusions from this formation in the knob is most astonishing. There are some larger masses of shale involved with the lava, but they can hardly be regarded as inclusions. There may be some content of comminuted shale in the lava, the evidence for or against this not being decisive.

STRUCTURAL FEATURES: SHEAR ZONES

The dissection of the knob by quarrying operations has brought to light some structural features which were not discernible before. Woodworth found evidence of interrelations of lava and shale which suggested faulting of the knob to him, and the opening of the knob has brought to light much more evidence of the same sort, and evidence of severe compressive disturbance and dislocation exists all through the lava mass. A few sketches and a comparison of them with the photograph of the knob (plate 10) will assist in the exposition of the observed relations.

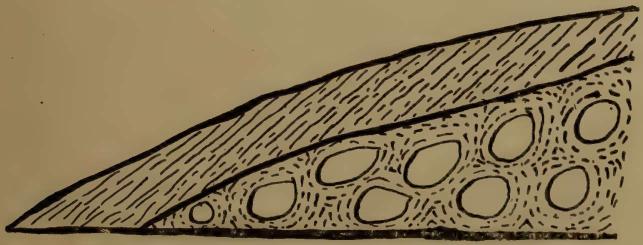


FIGURE 1.—*Shale overlying Lava on low Point projecting from Starks Knob*

Showing in the photograph at the base of the knob just to the right of the boiler-house. This shale wedges out into the lava of the knob; in other words, shows lava both above and below it. It is not a contact between lava and overlying shale, but a shale wedge within the lava mass.

Figure 1 is a sketch of the relations shown in a low point which projects out to the east from the base of the knob, and which has remained unquarried because of the shale overlying the lava, so that there is no great thickness of the latter above ground. A short distance to the south of this point, back of the boiler-house, is another similar one in which the rock relations are just reversed, lava overlying shale. In this latter case it is not certain whether the shale marks the actual base of the lava or whether it is just another shale wedge.

In figure 2 a wedge of shale in the southern portion of the knob is sketched. It is probably squeezed up into the lava from the shale which underlies it on the west side. This especial wedge is excessively mashed and slickensided and the material may be in part derived from the lava.

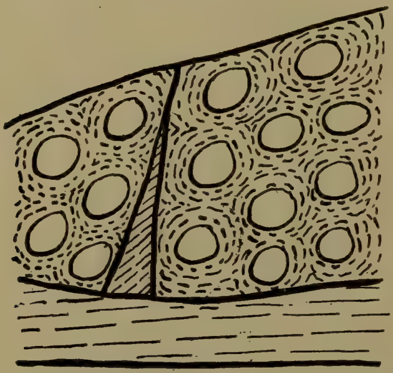


Figure 2.—*Nearly vertical Wedge of Shale enclosed in Lava of Starks Knob*

It does not show clearly in the photograph, but lies toward the left end of the exposed face, nearly over the projecting point sketched in figure 1.

At the north end of the knob a long point remains unremoved because of the included shale wedge sketched in figure 3. This wedge was plainly near the top of the lava, no great thickness of which ever lay above it.

The surfaces of the lava adjoining the vertical wedge of shale shown in figure 2 are highly smoothed, polished, and slickensided. The striation on these surfaces is nearly horizontal, showing that these two parts of the knob have been pushed past one another laterally under conditions of considerable load. This zone of shearing bears northwest-southeast. Zones parallel to this run through the knob, though lacking included shale, and in all cases with the highly slickensided surfaces showing nearly horizontal striations.

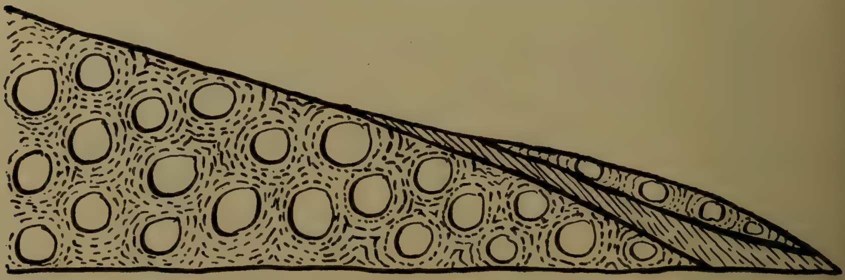
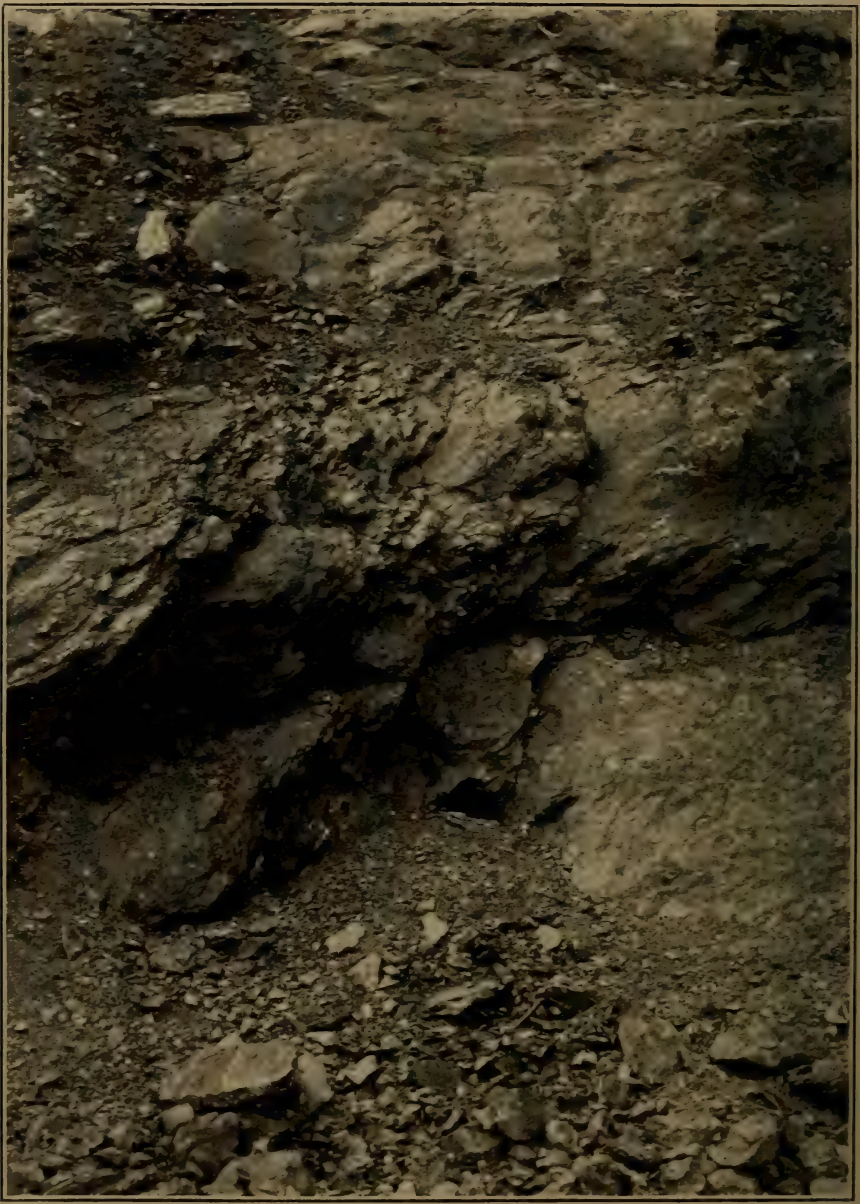


Figure 3.—*Sketch of Shale Wedge enclosed in Lava at the north End of Starks Knob*

A long projecting point remains unquarried here, the inner portion of which shows at the extreme right in the photograph, the remainder being without the field of view

In the northern half of the knob the excavations have brought to light another great shear zone, also nearly vertical, but bearing north-south. In this we have again the same thorough slickensiding, and again the striations are nearly horizontal, in no observed instance departing more



SHEARED AND SLICKENSIDED SHALES NEAR BASE OF STARKS KNOB

The photograph shows the shales as they appeared in August, 1910. The spot photographed may be seen in the previous plate near the base of the knob and just to the right of the cable which extends down the face.

than 20° from it. These two masses have also suffered lateral relative displacement under conditions of load.

In addition to these two great zones are many minor planes of shearing throughout the knob, all with slickensided faces and with striations approaching the horizontal.

During 1910 quarrying work at the knob was in such stage as to expose great sheared surfaces in the central part of the knob. The sheared material had considerable thickness, 3 to 4 feet at least, and consisted of a mass of shaly, thin curved plates, beautifully slickensided on all surfaces for the entire exposed thickness. At the time it did not occur to us that this was the base of the trap, and we interpreted it as a great shear zone which cleaved the knob diagonally from base to summit, since it had an easterly inclination of some 40° and apparently passed clear through the knob. Plate 11 is a photograph of a portion of this sheared surface, showing a considerable thickness of the material. At subsequent visits these surfaces had become covered by quarry debris and showed but poorly. We learned, however, that the material had been drilled into to a depth of 12 feet in search of lava underneath, but that none had been forthcoming. This leads to the belief that this is really underlying shale and marks the actual base of the lava. The material does not exactly resemble the ordinary shale, and there is some reason to believe that some lava has been sheared in with the shale. In this zone, also, the striations approach the horizontal.

There is still one more indication of dislocation in the knob; its back seems to be broken. This becomes quite evident to the observer who stands on the summit and looks down into the excavation. The main shear zone in the northern half of the knob trends north 10° east, and this is also the trend of the lava mass there. The southern half of the knob, however, trends north 45° west, and its shear zone likewise. The knob appears as if cracked in two midway and the two halves dislocated through an angle of 55°. From the highest point of the knob, as shown in the photograph, a line carried nearly vertically down the front, with just a slight inclination to the right, will separate the knob into these two halves.

All the evidence indicates that the lava of the knob has experienced compressive dislocation of the same type as have the overthrust shales in whose midst it lies; of the same type and quite comparable in amount.

If the great diagonal shear zone just described lies at the actual base of the lava, then the latter forms a sheetlike mass, inclosed in the shales, and dipping in conformity with them, as sketched in figure 4. This corresponds with Woodworth's original conception of the relations of the lava and shales.[4] The present relief of the knob is due to erosion, the lava being more resistant than the inclosing shales. The shale wedges inclosed in the lava may be due to lava tongues running out into the shales from the main mass, but more probably they are due to dislocation, to a breaking up of the lava mass by faulting and shearing, with interleaving of masses of shale.

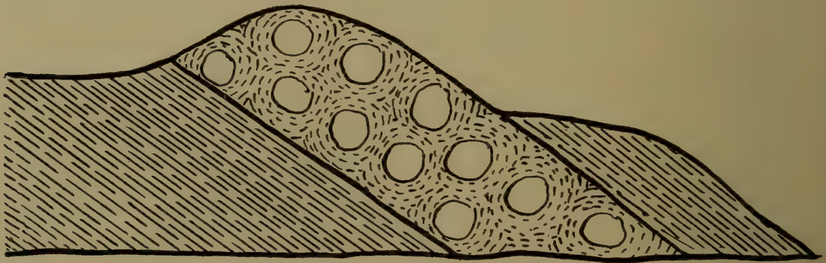


FIGURE 4.—*Diagram illustrating Relations of Lava and enclosing Shales of Starks Knob*

The lava forms a sheetlike mass dipping to the east with the shales at an average angle of about 35°

The lava then seems to lie within the shales after the manner of an intrusive sheet; but it is altogether too short for a sheet. It is cut off in very abrupt fashion on the north; a trench cut in the rock on that side, just beyond the knob, shows nothing but shale. On the south it is cut off nearly as abruptly. Moreover, the nature of the lava itself, the ball structure and the pitchstone, decisively negative any notion that we are dealing with a sheet. It indicates either a surface flow or a volcanic neck.

MICROSCOPIC CHARACTER

There are two chief varieties of the rock of the knob—the finely crystalline, dull, black rock of the lava balls, and the intervening pitchstone. Both are locally amygdaloidal; but all such material seen by us was found loose on the dumps, and such as had frequent amygdules was not abundant. The study of the exposures has led to the belief that the balls may have originally possessed a glassy crust, and this was Woodworth's belief also. But if so, this has been sheared away by subsequent movements, and at present all glassy material is between the balls. The bulk of it has been greatly mashed and sheared. The balls also invariably show slickensided exteriors.

Thin-sections from the balls show a network of minute feldspar laths, set in what was in some cases certainly, and in all cases probably, a glass base. In the fine-grained rock from the margins of the balls the laths have a prominent radial or spherulitic arrangement; the somewhat coarser rock from the centers shows the same arrangement, but less prominently. The laths are minute and not greatly twinned. In the coarser varieties extinctions up to 20° are shown, and the feldspar is probably andesine-labradorite.

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[4] 21st Rept. New York State Geology, figure 2, p. r19.

In none of the slides is there any determinable pyroxene. In the finer-grained rock it is quite certain that no pyroxene ever crystallized out; in the coarser rock a trifle may have done so, as there are small, scattered patches of calcite and other alteration products between the feldspars, which may have resulted from the alteration of small pyroxenes. But this is not thought probable, and, in any event, the amount is small.

In all of the slides there are occasional altered areas which have the polygonal outlines of porphyritic crystals. Many of these have the shapes and angles of olivine, and all are probably original crystals of this mineral. The usual alteration is to a chlorite aggregate, often with traces of the mesh structure of serpentine; but sometimes the mineral is replaced by crystalline calcite.

Much opaque material is seen in all the slides. There is a little pyrite in small but determinable crystals. There is much finely divided, black matter, which may be magnetite, though none of it shows the characteristic luster of that mineral, being perhaps too minute. But the most characteristic opaque mineral in the slides presents optical characters new to our experience. The chemical analysis suggests that it is graphite, or some graphitoid mineral, and such it most probably is; but its luster is entirely different from that of ordinary graphite. It shows instead in reflected light an even, light gray sheen, quite unlike the appearance which metallic lustered minerals show.

All the slides contain much calcite. It fills the amygdules, solidly welds up the host of cracks which ramify everywhere through the lava, and also occurs in irregular patches through the lava. In some of the amygdules a little quartz accompanies it. At a rough estimate, it forms between 5 per cent and 10 per cent of the mass of the knob. It gives eloquent testimony to the shearing which the knob has experienced. The calcite filling cracks shows everywhere prominent undulatory extinction and polysynthetic twinning, such as are characteristically developed in this mineral under compressive stress.

The limestone inclusions in the balls have had a slight chilling effect upon the lava, producing a border of clear, green glass, packed with finely divided, black, opaque matter. A slight amount of corrosion has occurred, the limestone border being etched away, fragments separated and inclosed in lava and in whole or in part dissolved. The border of the limestone, against the lava, is more coarsely crystalline than the remainder and is also packed with the fine, opaque material, which is evidently a product of the corrosion, as elsewhere both limestone and lava are free from it.

The pitchstone which occupies the spaces between the balls is found massive and uncrushed only when protected by limestone inclusions. It consists of clear, green glass, so precisely like that formed in similar situation in the balls as to suggest a like origin. The field evidence is plain that the pitchstone has had much more powerful corrosive action on the limestone of the inclusions than the lava of the balls had; hence the much greater quantity of this glass in the pitchstone. Except for an occasional pyrite and frequent nests of abundant, tiny, opaque matter, there is no sign of any crystallization.

CHEMICAL COMPOSITION

Since the rock from the centers of the large lava balls seemed in quite fresh and unaltered condition, except for the olivine, it was confidently expected that a chemical analysis would definitely show the composition of the lava and would be attended by no especial difficulty; but analysis developed the presence of a considerable amount of carbon in the rock, rendering determination of ferrous iron very difficult, and showed also the presence of a large quantity of water. This also was difficult of exact determination. But Professor Morley has labored indefatigably at the problem. The ferrous iron was finally determined by bichromate titration. Professor Morley states that the results can not be vouched for to the single drop, as with permanganate, but that the uncertainty is not great; that he can not hope that the accuracy of the three determinations—Fe_2O_3, FeO, and H_2O+—is as great as that of the others, but that he has every reason to believe in their reasonable accuracy. Our indebtedness to him for the painstaking labor and the eventual very satisfactory result is most emphatically expressed.

The water is no doubt present as a constituent of the glass. The interest attaching to the presence of carbon more than compensates for the slight uncertainty introduced into the analysis.

SiO_2	47.55
Al_2O_3	16.65
Fe_2O_3	4.94
FeO	5.12
MgO	5.63
CaO	4.77
Na_2O	4.20
K_2O	2.52
H_2O+	5.57
H_2O-	0.24

TiO_2	0.87
P_2O_5	0.27
Cl	0.10
F	0.06
S	0.01
MnO	0.46
C	0.80
$CaCO_3$	0.34
Total	100.10

Selected rock from the center of one of the large lava balls, as free as possible from calcite. E. W. Morley analyst.

The calculated norm of the rock would be

Orthoclase	15.01	Olivine	12.64
Albite	33.01	Magnetite	7.19
Anorthite	18.90	Ilmenite	1.67
Nepheline	1.42	Apatite	0.67
Diopside	2.48		

Totaling 92.99 per cent, the residue consisting of water, carbon, and calcium carbonate.

The rock classifies in

Class 2, Dosalane;	Rang 3, Andase;
Order 5, Germanare;	Subrang 4, Andose.

It is thus a member of a very large rock group of diabasic or basaltic composition. It is quite near some of the Newark traps—that from Medford, Massachusetts, analyzed by Merrill, for example—though it is a more basic rock than the average Newark traps, which run from 52 to 53 per cent of silica.

The carbon content was a wholly unexpected result. Gaseous compounds of carbon are emitted by most cooling lavas, but a considerable carbon content in the cold lava is most exceptional. Inquiry as to its source is naturally suggested.

The knob is surrounded by black shales and these at once suggest themselves as a possible source. There are no recognizable shale inclusions in the lava, but it might be possible that the explosive action of the eruption should have mingled a certain content of comminuted shale with it. The thin-sections, however, give no suggestion of any such admixture, no shale particles being recognizable in them. And when it is recalled that in such black shales the entire content of carbonaceous matter does not usually exceed 5 per cent of the rock, it will be seen that the rock at the knob would of necessity contain from 15 to 20 per cent of shale, in order to give the carbon percentage shown on analysis, provided it came from this source; but neither the thin-section nor the chemical analysis gives any suggestion of such an admixture.

A trifling amount of carbon may have been obtained from dissolved limestone, as this contains a small amount of organic matter, and the abundant opaque particles developed in the glass at the limestone contacts definitely suggests something of the sort; but there is no evidence of a large amount of limestone corrosion, and the rock is low in lime, rather than high. It could not have obtained much carbon from this source.

There remain apparently two possible sources for the carbon. The heat of the intrusion may have liberated hydrocarbon from the shales below ground, which were then taken up by the lava, or the lava itself may have contained more carbon than usual originally, more than could be oxidized by the usual volcanic processes. Either process is unusual, but then the occurrence is itself unusual. Graphite does occur in igneous rocks; as, for example, in some of the Adirondack pegmatites. Its occurrence in meteorites is well known. It is quite possible, therefore, that it is here one of the primary minerals of the lava; but the large amount present, together with the rarity of its occurrence in igneous rocks, enforces caution in attributing such a source to it. In so far as possible derivation from the shale is concerned, it must be stated that the associated shales in the vicinity of the knob show no indication of any loss of carbon due to action of the lava, or indeed of any change whatever, so that if we look to them as a source we must assume that the process only took place at greater depths. It would be a debatable question whether hydrocarbons, liberated from the shales by the heat of the intrusion, would migrate into the lava; whether they would not rather be driven away from it. Even if taken up, why should they have been converted to graphite? All, or nearly all, lavas contain carbon; but on cooling they give it off in combination with oxygen or with hydrogen. Why an exception was made in this case we can not say.[5]

Is the Lava in Place?

Starks Knob is a small mass of igneous rock inclosed in shales which are everywhere greatly folded and sheared, and which the evidence, both structural and paleontologic, shows to have been overthrust into the district from the east. The question naturally arises, May not the lava itself have been overthrust into the region along with the inclosing shales? We can not definitely answer this question, but we must emphasize its possibility. Were it the fact, certain of the structural features would receive a simple explanation. As a result of the overthrusting the weak shales have become a jumble of small separate masses of varying age. The grit bands have been rent asunder and now occur in widely separated fragments through the shale, after the manner of inclusions. In such a mixture a fragment from some mass of igneous rock could easily be carried. The shearing and dislocation of the lava, its abrupt lateral terminations, the lack of dikes running out into the surrounding shales, and the shale wedges in the lava would all be simply and readily accounted for. More especially the difficulty of accounting for the inclusions in the lava, abundance of one type of limestone fragments and entire lack of inclusions of all other sorts, more especially those of shale, would be much diminished. The manner of occurrence in the shales, also, as a short and comparatively thick mass which follows down the dip of the shales, would not be so difficult of comprehension. The shales are so cleaved that they usually come apart more readily on the cleavage planes than on the stratification. It is this character that makes it so difficult to collect fossils from them. It would seem that the explosive action occurring on the formation of a volcanic vent through them would have opened them vertically along the cleavage planes instead of following the inclined stratification slope.

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[5] Dr. H. S. Washington has been so kind as to examine the thin-sections of the rock of the knob, and the black, insoluble residues obtained chemically. His comments were received too late to be inserted in the paper. Under date of May 25, 1913, he writes: "The black material is certainly carbon, but is not graphite. The idea has occurred to me that its presence is *possibly* due to reduction of CO_2 by FeO, the CO_2 supplied from the limestone inclusions. This seems a rather wild hypothesis, but is suggested by the appearance of the sections where the carbon is about the mafic minerals and not in the feldspar. I have talked it over with Hostetter, who is working on the iron silicates, and he says that it is possible, given proper temperature and pressure, for FeO to reduce CO_2; to what extent, of course, is uncertain, and dependent upon conditions."

If the lava solidified where it now rests, the only possible explanation of the occurrence is that we have here a volcanic throat or neck. The nature of the rock and the small lateral extent of the mass render it certain that it is neither an intrusive sheet nor a flow. But volcanic necks are usually nearly vertical instead of quite inclined, as in this case; they usually cut across the bedding instead of following it, and they are commonly filled with agglomerate, tuff, or solid lava. We recall no account of a neck filled with such material as that at Starks Knob. The usual filling is much more distinctly fragmental in type and more diversified in character. On the other hand, we know of no reason why material such as that at the knob might not accumulate in a volcanic neck.

Many features of the knob forcibly recall the characters of pillow lavas, characters shown to be produced (in many instances at least) in surface lavas when poured out so that they mingle with surface waters. Spheroidal structure, production of glass, and explosive mixture with fragmental material from beneath, are prominent features of such lava-flows. The great number of shrinkage cracks which everywhere cut the lava balls is another feature possessed in common.

There is no sign of the basal admixture with fragmental material, such as is found in many pillow lavas, at Starks Knob. But the base is not well exposed and, moreover, has been enormously sheared. An analysis of this basal, sheared material does suggest a possible mixture of lava and shaly matter in its make-up, but this is not at all certain. The lava is not as highly altered as most pillow lavas are, but this difference may be more apparent than real. Most such lavas have been described from natural exposures and exteriorly the lava at the knob was greatly altered. The present fresh material was obtained from well within the knob, available because of the quarrying.

Nor is the structure precisely comparable to that of pillow lavas, the chief difference being in the much greater quantity of intervening matter separating the ellipsoids at the knob; but there has been much shearing. All the balls show slickensided exteriors and the greater part of the intervening matter has been greatly sheared. It is highly probable that the quantity of intervening material has been much increased by this means, the outer, glassy portions of the balls being thereby sheared away.

In attempting to weigh the evidence for or against the lava being in place or being an overthrust mass, we must confess our inability to come to any definite conclusion in the matter. The latter view seems *a priori* so unlikely that our sympathies are entirely with the other. Yet the similarity of the material to a fragment of a surface flow embedded in the shales is so great and contrasts so strongly with the usual characters of a volcanic neck that we can not relieve ourselves from the suspicion that it is after all a fragment of a surface flow which was poured out on a surface of Bald Mountain limestone, probably under water, and was subsequently thrust westward to its present position. Under either view there is no other mass with which to compare it. If it is in place it represents the only intrusion of its type or of its age that is known within the State or anywhere in the vicinity. If it is an overthrust fragment, no other fragments are known. They may be buried from sight elsewhere in the thick mass of the overthrust shales or they may have been entirely eroded away.

THE INCLUSIONS

The difficulty of accounting for the limestone inclusions has been already stated. The inclusions are many and all of the one kind of rock, rock which seems referable to the Bald Mountain limestone perhaps, but certainly to no other of the formations of the region. Just what the thickness of the overthrust shales may be at the knob we have no means of knowing, but they extend 5 miles farther to the westward before being replaced at the surface by the undisturbed Canajoharie shales of the indigenous rock series; hence quite likely their thickness at the knob is considerable, some hundreds of feet. In considering the manner of overthrusting of such weak shales, it seems reasonable if not obligatory to suppose that the thrust was transmitted by some strong, competent rock stratum on top of which the shales were carried westward. This stratum might carry as far west as the shales, or not quite so far, a jumbled mass of shales extending somewhat beyond it. The Bald Mountain limestone is the first competent formation of this sort beneath the Normanskill shales in the overthrust section, and it is therefore not unreasonable to suppose that it may be present underground at the knob. If so it would be nearest the surface of any of the limestone or dolomite formations of the region, with soft shales above it, and also below it if it rests on the Canajoharie, as is probably the case. Hence fragments of it could be easily carried upward in the lava. The lack of shale inclusions is not thus explained, nor the lack of inclusions from the more deeply buried formations, such as the Little Falls dolomite and Potsdam sandstone. If the drill should show that the Bald Mountain limestone was present at no great depth below ground at the knob, or if, on the other hand, it should show that it was not present at all, nor any other similar limestone formation, we should have more definite data for deciding whether the knob was exotic or not; but the drill has not been at work in the vicinity. With our present knowledge, it seems to us the inclusions are most simply explained on the view that the knob is an overthrust fragment of a surface flow poured out on limestone, though it is an open question whether under such conditions the limestone would have been likely to undergo as much corrosion as it has experienced.

AGE OF THE IGNEOUS ROCK

The question of the age of the lava is obviously connected with the question as to whether it is *in situ* or is not. If in place, it must be younger than the Ordovician shales which it cuts. If not in place, this is not necessarily true, though it is probably so. There exist in New York two groups of igneous rocks which fulfill this age requirement—the basic dikes of the Champlain Valley and of central New York and the traps of the Newark series. When Woodworth and Cushing discussed this matter at the time of the original description of the knob, a dozen years ago, they independently suggested a Newark age as most probable. The rock is much more like the Newark traps than it is like the basaltic dikes of the Champlain Valley or the peridotites of central New York, and a reference to a known group of igneous rocks seemed to us a more probable one than the alternative of considering this as the single representative known of igneous action of other date in the vicinity.

More recently Kemp, from his study of the mineral waters of the Saratoga region, some of whose constituents impress him as of probable deep-seated origin, has suggested the possibility that Starks Knob has some significance in the matter and may perhaps be of Tertiary age.[6]

A reference to the Newark still seems to the writer the most logical view to take in default of positive evidence to the contrary. If the lava has been overthrust, it may well represent a fragment of a Newark flow, to some of which it has a strong resemblance, as originally pointed out by Woodworth. That would mean that the date of the overthrusting must be later than the Newark; but when one contemplates the amount of deformation which the Newark rocks have everywhere experienced, there is no especial difficulty in that assumption. In any event the amount of deformation which the knob has undergone seems a positive evidence of antiquity. The deformation must have taken place under load, since removed by erosion. The lava is of the effusive type; since being extruded it has been buried, deformed, and then uncovered. To be sure, it lies along the axis of a main valley of erosion, surrounded by relatively weak rocks, so that conditions are favorable to rapid wear; and glaciation may have been an important factor in the process. But even making every allowance for that, it seems to us that, from this one standpoint alone, the oldest Tertiary is the youngest age that could be ascribed to the lava with any degree of probability. And since Tertiary igneous rocks have been nowhere demonstrated in the country east of the Mississippi, the Newark age seems to us the more probable. Yet we candidly admit the peculiarity of the rock and its isolated occurrence and have no quarrel with any one disposed to take a different view. It can be legitimately argued that the Saratoga Springs are also peculiar and isolated, and that their existence in the same region with the knob is not likely to be ascribable to pure chance.

To sum up, the knob consists of a small mass of lava of distinctly effusive type. If it is in place, it seems surely a volcanic neck, though it has many characters unlike those of most necks; if not in place, it seems surely a fragment of a surface flow, overthrust into the district from somewhere farther east. If in place, it is younger than the date of the overthrusting, though it may have been somewhat deformed by the final stages of the process; if not in place, it is older. If not in place, we have no definite idea whence it came, nor are any similar fragments known. It has some features in common with certain Newark trap flows and is like some of them in composition. Clear evidence of much shearing of the knob, of such type as to indicate deformation under load, leads to the conviction that the lava can not be an especially recent one. It is noteworthy for its large content of carbon.

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[6] Bull. 159, New York State Museum, pp. 61-62.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

ALEXANDRIAN SERIES IN MISSOURI AND ILLINOIS[1]

BY T. E. SAVAGE

(Presented by title before the Paleontological Society December 31, 1912)

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INTRODUCTION

The name Alexandrian series[2] was proposed by the writer in 1908 in order to provide a place for the earliest Silurian strata occurring in Illinois and eastern Missouri which occupy a position above the top of the generally accepted Cincinnatian (Richmond) and below the Brassfield (Ohio Clinton) limestone.

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[1] Manuscript received by the Secretary of the Geological Society May 9, 1913.
[2] T. E. Savage: Am. Jour. Sci., vol. xxv, 1908, p. 434.

Regarding the stratigraphic position of the Brassfield. Professor Schuchert[3] states in his classic work on the Paleogeography of North America that "in the Anticosti section it is seen that this so-called Clinton (Ohio Clinton) or *Triplecia ortoni* zone is older than the true Clinton of the Appalachian region." It is now also known that the fauna of the Brassfield limestone is very closely allied to that of the earlier Silurian strata of Illinois and eastern Missouri, as shown in the similarity of several of the genera and species to those of the older Edgewood limestone. For this reason the strata representing the Brassfield in Illinois and Missouri are here included in the Alexandrian series.

As thus defined the Alexandrian series embraces all of the strata in this region between the top of the Cincinnatian (Richmond) and the top of the Brassfield limestone. It includes strata that have been referred to in the literature under various formation names, as the Girardeau limestone, Bowling Green limestone, Noix oolite, Edgewood limestone, Sexton Creek limestone, Channahon limestone, and Essex limestone. Some of these strata have been assigned to positions in the geological column as widely separated as the Trenton division of the Ordovician and the Onondaga of the Devonian system.

In 1857 Billings proposed the name Middle Silurian—"Anticosti group" [4]—for the succession of strata exposed on the island of Anticosti, in the Gulf of Saint Lawrence. In the lower part of his Anticosti group Billings included the representatives of Ordovician strata to which the name Richmond has since been applied. In the upper part were included strata equivalent to the entire Niagaran series of the New York section, and in the middle portion were strata belonging to the interval between the Richmond below and the Niagaran (New York Clinton) above, to which has been given the name Alexandrian series. Since the Anticosti group, as defined by Billings, embraced at the base such an important part of the Cincinnatian series as the Richmond and in the upper part the whole of the Niagaran series, this term is not considered appropriate or in any sense to have priority as a name for only that portion of the Anticosti section belonging to the interval between the Richmond of the

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[3] Charles Schuchert: Paleogeography of North America. Bull. Geol. Soc. Am., vol. 20, pp. 427-606.

[4] E. Billings: Geological Survey of Canada. Report of Progress, 1857, pp. 247-255.

Ordovician and the New York Clinton of the Silurian to which the name Alexandrian series has been applied.

Distribution of Strata

The rocks representing the Alexandrian series in Illinois and eastern Missouri appear at the surface in two general areas that are separated by a distance of 200 miles. One area borders both sides of the Mississippi River from about the mouth of the Ohio River north nearly to Hannibal, Missouri. Within this belt outcrops occur at intervals over a width of 25 to 40 miles. Good exposures have been studied in Alexander and Union counties, Illinois, and in the vicinity of Cape Girardeau, Missouri. North of the fault-line that crosses the south end of Jersey and Calhoun counties, Illinois, and west into Lincoln County, Missouri, strata representing some part of this series outcrop at a number of places over the east part of Lincoln, Pike, and Ralls counties, Missouri, and in Jersey, Calhoun, and Pike counties, Illinois, within a distance of 12 to 20 miles from the Mississippi River.

The second area in which these early Silurian rocks are exposed in the upper Mississippi Valley is in Will and Kankakee counties, in northeastern Illinois, where somewhat isolated outcrops of the Sexton Creek (= Brassfield) limestone and earlier Silurian strata appear at a number of places in the vicinity of Kankakee and Desplaines rivers. It is probable that the Alexandrian strata in the Mississippi River area and in northeast Illinois are more or less continuous, probably along the present basin of the Illinois River, but they are concealed beneath younger deposits in the intervening region.

Earlier Studies and Interpretation of the Strata

In a report in 1855, Mr. G. C. Swallow,[5] who was then State geologist of Missouri, noted the white oolite bed in the vicinity of Louisiana, Missouri, and referred it to the Onondaga of the Devonian.

In the same report Shumard[6] described a limestone occurring near Cape Girardeau, Missouri, under the name Cape Girardeau limestone, and considered it the oldest Silurian formation in the State.

In discussing the stratigraphic geology of Illinois in 1866, Worthen[7] recognized the Girardeau limestone in the vicinity of Thebes, but referred it to the Ordovician in the upper part of the Cincinnati group.

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[5] G. C. Swallow: Geological Survey of Missouri. Reports 1 and 2, 1855, p. 107.

[6] B. F. Shumard: Geological Survey of Missouri. Report 2, 1855, p. 154.

[7] A. H. Worthen: Geological Survey of Illinois, vol. 1, 1866, p. 130.

On a later page of this report Worthen correlated with the Niagara of northern Illinois the gray limestone forming the lower part of the Mississippi River bluff in the southwest part of Pike and the northwest part of Calhoun counties in Illinois (now known to be of Sexton Creek or Brassfield age).

On another page he assigned to the Lower Helderberg group the dark limestone and the overlying mottled red and gray limestone in the vicinity of Thebes that represent respectively the Edgewood and the Sexton Creek limestone in that portion of the State. He says:

> "It would appear probable that no beds of undoubted Niagara age were ever laid down in southern Illinois, but in their places these siliceous limestones, representing in part the age of the Lower Helderberg limestones and in part the Oriskany sandstones of the New York series, were deposited resting directly upon the Cincinnati group of the Lower Silurian."

In a report on the Geology of Alexander County,[8] Illinois, published in 1868, the Girardeau limestone is again assigned to the Cincinnati group, while the overlying gray limestone, containing *Dalmanites danai* and its associates, is referred to the Lower Helderberg.

In a paper presented to the American Association for the Advancement of Science in 1870 Worthen[9] again discussed the limestones occurring between the Clear Creek (= Oriskany) beds and Cape Girardeau limestone in southwest Illinois. He concluded that

> "these limestones represent the same geological horizon as the Niagara dolomites in the northern part of the State; and that the difference in the specific character of the fossils is entirely due to the changes in the oceanic conditions under which they were deposited, and not to the different ages of the sediments themselves."

In describing the geology of Calhoun and Pike counties, Illinois, in 1870, Worthen[10] considered the gray limestone (= Sexton Creek or Brassfield) appearing in the lower part of the Mississippi River bluff, from near the town of Rockport south to Hamburg, as the equivalent of the Niagara limestone in the northern part of the State. He regarded as the basal member of the Niagara in this region the gray oolite and the overlying buff magnesian limestone outcropping a few miles below Hamburg and that are now known to correspond to the Edgewood as developed near Louisiana, Missouri.

In his description of the geology of Will and Kankakee counties, in

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[8] A. H. Worthen: Geological Survey of Illinois, vol. iii, 1868, pp. 20-32.

[9] A. H. Worthen: Proc. Am. Asso. Adv. Sci., vol. xix, 1870, p. 172.

[10] A. H. Worthen: Geological Survey of Illinois, vol. iv, 1870, pp. 6, 7, and 26.

1870, Worthen[11] did not distinguish the Alexandrian series from the Niagara limestone.

In a report on the Geology of Lincoln County, Missouri, published in 1873, W. B. Potter[12] referred the oolite present in the ridges and knobs in the northeast part of this county to the Onondaga of the Devonian.

In a paper entitled "A remarkable fauna at the base of the Burlington limestone in northern Missouri," in 1892, Dr. C. R. Keyes[13] distinguished the white oolite bed and the overlying buff or brown limestone exposed near Louisiana and correlated them with the Niagara limestone of Iowa.

In describing the vertical range of fossils at Louisiana, Missouri, in 1897, Keyes and Rowley[14] again referred the oolite bed and the associated buff limestone in this region to the Niagara.

In the following year Keyes[15] published a paper on "Some geological formations of the Cap Au Gres Uplift," in which the name Noix oolite was proposed for the white oolite bed in the vicinity of Louisiana, and the term Bowling Green limestone was given to the buff magnesian limestone near Bowling Green, Missouri. Of these formations Keyes writes:

> "The Noix oolite and the Bowling Green limestone together may be regarded approximately as equivalent to the so-called Niagara of the Upper Mississippi basin."

In his report on the geology of Pike County, Missouri, in 1907, R. R. Rowley[16] says:

> "The Silurian is represented by a white oolitic and a brown limestone. The oolitic limestone attains a thickness of about 7 feet, and from its fauna is thought to belong to the Clinton. The brown limestone overlies the white oolitic and attains a maximum thickness of 25 feet. This horizon is clearly Niagara."

In a paper by the writer[17] in 1908 a bed of cherty and mottled limestone in southwestern Illinois was recognized as the equivalent of some part of the Brassfield limestone of Ohio. A distinct formation of early Silurian time was also shown to be present in this region below the Brassfield and above the Girardeau and separated from each by a sedimentary break. The Silurian aspect of the fauna of the Girardeau limestone was emphasized, and the name Alexandrian series was proposed to embrace these post-Cincinnatian and pre-Clinton beds represented by the Girardeau limestone and the succeeding strata lying below the equivalent of the Brassfield limestone.

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[11] A. H. Worthen: Ibid., pp. 6, 7, 26, and 207-240.

[12] W. B. Potter: Geological Survey of Missouri, 1873, p. 242.

[13] C. R. Keyes: Am. Jour. Sci., vol. xliv, 1892, p. 447.

[14] Keyes and Rowley: Proc. Iowa Acad. Sci., vol. iv, 1897, pp. 26-40.

[15] C. R. Keyes: Ibid., vol. v, 1898, pp. 58-63.

[16] R. R. Rowley: Missouri Bureau of Geology and Mines, 2d ser., vol. viii, 1907, p. 20.

[17] T. E. Savage: On the Lower Paleozoic stratigraphy of southwestern Illinois. Am. Jour. Sci., vol. xxv, May, 1908, pp. 431-443.

The following year the name Sexton Creek limestone was defined[18] for the Silurian strata in Illinois that are equivalent to some part of the Brassfield. The term Edgewood limestone was at the same time applied to that part of the Alexandrian series in western Illinois and eastern Missouri lying between the Girardeau and the Sexton Creek limestones.

In discussing the "Faunal succession and the correlation of the pre-Devonian formations of southern Illinois" [19] in 1910, the significance of the Silurian types of fossils in the Girardeau limestone was pointed out, and the Channahon limestone, in Will County, was regarded as the equivalent of some part of the Edgewood formation of southern Illinois and eastern Missouri.

In a paper read at the 1911 meeting of the Illinois Academy of Science, the Essex limestone,[20] in Kankakee County, was described and the formation was provisionally referred to the Alexandrian series above the Edgewood and below the Sexton Creek limestone.

General stratigraphic Relations

The strata comprising the Alexandrian series in Illinois and Missouri are everywhere unconformable on some horizon of the Richmond, and they are separated by a similar sedimentary break from the rocks that lie above them.

In the south part of the area, in Alexander and Union counties, Illinois, and Cape Girardeau County, Missouri, these strata rest on different levels of the Orchard Creek shale of Richmond age, and are followed by Helderbergian limestone having the faunal aspect of the New Scotland of New York.

Farther north, in Jersey, Calhoun, and Pike counties, Illinois, and Lincoln, Pike, and Ralls counties, Missouri, the Alexandrian overlies a blue shale that in Illinois has been correlated with the Maquoketa, and in Missouri has been called Hudson River shale and Buffalo Creek shale, the upper part of which corresponds to the Orchard Creek shale of southern Illinois. The rocks that overlie the Alexandrian strata in Jersey and Calhoun counties, Illinois, and across the river in the northeast part of Lincoln County, Missouri, are Devonian limestones of Hamilton age belonging to the Iowa or northwest (Dakota) province. A few miles still farther north, in the vicinity of Pleasant Hill, Illinois, and Louisiana, Missouri, they are immediately succeeded by a bed of dark shale of Upper Devonian age.

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[18] T. E. Savage: The Ordovician and Silurian formations in Alexander county, Illinois. Am. Jour. Sci., vol. xxviii, December, 1909, pp. 509-519.

[19] T. E. Savage: Illinois State Geological Survey. Bull. No. 16, 1910, pp. 302-341.

[20] T. E. Savage: The Channahon and Essex limestones in Illinois. Trans. Illinois Acad. Sci., vol. iv, 1912, pp. 97-103.

In the northeastern Illinois area the Alexandrian strata rest on the Maquoketa shale and, where exposed beneath superjacent strata, they are followed by dolomites of Niagaran age.

DETAILED STRATIGRAPHY OF THE ALEXANDRIAN SERIES

THICKNESS AND FORMATIONS OF THE SERIES

The strata comprising the Alexandrian series, as defined above, have a maximum aggregate thickness of about 175 feet. The series is divisible into four formations, which, with the possible exception of the Essex limestone, are unconformable among themselves, but their faunas are clearly related. The sequence of the formations from below upward is as follows: Girardeau limestone, Edgewood limestone, Essex limestone, and Sexton Creek (= Brassfield) limestone.

THE GIRARDEAU LIMESTONE

Occurrence and stratigraphic relations.—The name Cape Girardeau limestone was given to the formation by Shumard in 1855, from Cape Girardeau, Missouri, near which town the strata are well exposed. The shortened form of the name has been adopted for this formation.

The Girardeau limestone is present only in the south part of the area under consideration and is not known farther north than a few miles above Cape Girardeau, Missouri. It is well exposed in Illinois near the mouth of Orchard Creek about two miles south of Thebes, and in the bluff of the Mississippi River and in some cuts along the New Cairo and Thebes Railroad for some distance farther south. It also outcrops in the bank of Mississippi River and along the Chicago and Eastern Illinois Railroad 1½ miles north of Thebes. In Missouri these strata occur over a small area in Cape Girardeau County. They are well exposed at the type locality, about two miles north of Cape Girardeau.

In some places the Girardeau limestone rests unconformably on the Thebes sandstone (Richmond), and in other places it overlies different horizons of Orchard Creek (Richmond) shale. The rocks of this formation consist of dark, fine-grained, hard, brittle limestone, in layers

2 to 4 inches thick. Thin lenses of hard calcareous shale occur between the layers of limestone; both the limestone and the shaly partings in places contain numerous fossils. The total thickness of the formation is 35 to 40 feet.

Detailed section.—A representative section of the Girardeau limestone, exposed in the east bank of Mississippi River, 2½ miles south of Thebes, Illinois, is given below, beginning with (1) at the bottom:

Section of Strata 2½ Miles South of Thebes

	Feet	In.
3–5. Sexton Creek (Brassfield) limestone.		
5. Red or pink mottled, fine-grained, brittle limestone, in layers 8 to 36 inches thick, containing many fossils	8	10
4. Light gray, rather fine-grained limestone, with blotches of green shaly material and many nodules of chert; containing *Stricklandinia triplesiana* and *Triplecia ortoni* var	1	9
3. Chert bands, 2 to 4 inches thick, separated by 2- to 3-inch layers of hard, impure limestone, without fossils	5	6
A break in sedimentation.		
1–2. Girardeau limestone.		
2. Dark colored, fine-grained, hard, brittle limestone, breaking with conchoidal fracture, similar in all respects to number 1	15	..
1. Dark colored, fine-grained, hard, brittle limestone in layers 2 to 4 inches thick, separated by thin partings of calcareous shale, and furnishing the fossils listed below	18	..

In the foregoing section the two lower members represent the Girardeau limestone in its typical development, having at this place a thickness of 33 feet. The succeeding strata, members 3 to 5, inclusive, belong to the Sexton Creek (Brassfield) limestone, the two formations being separated by a sedimentary hiatus. The Edgewood strata which, north of Thebes, appear below the Sexton Creek limestone, are not present in this locality.

The species of fossils obtained from the Girardeau limestone are listed below:

Fossils from the Girardeau Limestone in Illinois and Missouri[21]

Archæocrinus sp.
Ptychocrinus splendens (S. A. Miller)
Tanaocrinus cf. *typus* W. and Sp.
Nematopora alternata Ulrich
Nematopora delicatula Ulrich
Nematopora fragilis Ulrich
Nematopora retrorsa Ulrich
Schuchertella missouriensis (Shumard)
Cornulites incurvus (Shumard)
Cornulites tenuistriata (Meek and Worthen)
Conradella sp.
Cyclonema concellata ? Hall

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[21] The species of fossils listed from the Girardeau limestone and the Edgewood formation are figured and described in Bulletin No. 20 of the Illinois State Geological Survey Reports.

Camarotœchia ? festinata Savage
Dalmanella modesta Savage
Homœospira immatura Savage
Leptœna rhomboidalis (Wilckens)
Lingulops ovata Savage
Protozeuga sulcocarinata Savage[22]
Rafinesquina ? mesicosta (Shumard)
Rafinesquina ? delicatula Savage
Rhynchotrema ? illinoisensis Savage
Diaphorostoma niagarensis var. *immatura* Savage
Modiolopsis concinna Savage
Pterinea formosa Savage
Acidaspis halli Shumard
Calymene dubia Savage
Cyphaspis Girardeauensis Shumard
Encrinurus deltoideus Shumard
Proetus princeps Savage

The decided Silurian aspect of the fauna of the Girardeau limestone appears in the list presented above. The post-Richmond age of the Girardeau limestone is shown by the fact that not a single characteristic Richmond species has been found in the formation, and also by the presence of such Silurian genera as Schuchertella, Homœospira, Camarotœchia (?), Diaphorostoma, Protozeuga, and Proetus. The only species in the Girardeau fauna that are listed by Cummings from the Richmond strata of Indiana, or that are known to occur in the Maquoketa (Richmond) strata of Iowa and Illinois, are *Leptœna rhomboidalis* and *Cornulites tenuistriata,* neither of which possesses any stratigraphic significance. It should be noted also that the most abundant and characteristic of tne Girardeau species, as *Schuchertella missouriensis, Rafinesquina ? mesicosta,* and *Protozeuga sulcocarinata,* continue upward into the succeeding Edgewood limestone. Regardless of whether the Richmond shall eventually be transferred from its present position in the Ordovician (where in the mind of the writer it should remain) to the Silurian system, the Girardeau limestone appears positively of post-Richmond age and clearly represents the earliest deposits of the early Silurian Sea that advanced into this region from the south, the epoch of submergence culminating in the Brassfield transgression.

THE EDGEWOOD LIMESTONE

Occurrence and stratigraphic relations.—The name Edgewood limestone was proposed in 1909[23] for the strata occurring between the Girardeau limestone and the Sexton Creek (=Brassfield) limestone in southwest Illinois and eastern Missouri.

In 1898, C. R. Keyes[24] proposed the name Noix oolite for the white oolite bed outcropping along Noix Creek at Louisiana, Missouri, and the name Bowling Green limestone for the brown magnesian limestone that is well exposed a few miles farther west, in the vicinity of Bowling Green.

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[22] Protozeuga has been defined in manuscript by Dr. W. H. Twenhofel for an early Silurian genus of brachiopods having the general characteristics of Waldheimia, but with punctate shells.

[23] T. E. Savage: Amer. Jour. Sci., vol. xxviii, December, 1909, p. 517.

[24] C. R. Keyes: Proc. Iowa Acad. Sci., vol. iv, p. 27.

Where the oolite is best developed, as at Louisiana, its fossils indicate that this bed is the equivalent of about the upper two-thirds of the Edgewood limestone as exposed in the vicinity of Thebes, Illinois, and of the corresponding part of the limestone present near the town of Edgewood, Missouri. It represents a local shallow-water phase of sedimentation in this region during only a part of Edgewood time. This was recognized by Keyes in the following statement:

> "The oolite (Noix) appears to be somewhat of a local phase, but is present not only in the vicinity of Louisiana, but all the way to Paynesville, a distance of 18 miles. The formation appears to be represented elsewhere in the vicinity by fossiliferous limestones that are not oolitic."

The strata to which the name Bowling Green limestone was applied consist of about 30 feet of brown, somewhat massive, limestone, the middle and upper parts of which contain few or no fossils, but the lower 1 or 2 feet carries a fauna similar to that found in the oolite at Louisiana and in the upper part of the fossiliferous portion of the Edgewood limestone in the vicinity of Edgewood, Missouri.

Inasmuch as the succession of strata from the base of the Edgewood to the top of the Bowling Green limestone appears to be unbroken, it is desirable to include all of these strata under a single formation name. For this more comprehensive series of deposits the term Noix oolite is not appropriate, because the oolite phase is developed only over a small part of the area of distribution of these strata, nor does it anywhere include the entire thickness. Nor is the name Bowling Green limestone desirable, for it was proposed for the limestone near Bowling Green, Missouri, which represents only the upper and mostly unfossiliferous portion of the Edgewood. On the other hand, the name Edgewood, as originally proposed, embraces all of the strata between the Girardeau limestone and the Sexton Creek (Brassfield) limestone in this region. The lower fossiliferous portion of the formation and the overlying brown, unfossiliferous Bowling Green phase are both well developed in the vicinity of Edgewood, Missouri, while the lowest beds of the Edgewood are not known north of this locality.

For these reasons the name Edgewood limestone is retained as the formation name, which includes all of the strata in Missouri and Illinois between the horizon of the Girardeau limestone and the top of the magnesian limestone near Bowling Green and the top of the brown limestone overlying the oolite in Lincoln, Pike, and Ralls counties, Missouri, and on the opposite side of the river in Illinois and their equivalents elsewhere in the Mississippi Valley.

It will be convenient, however, to subdivide the Edgewood into three members, as follows: (1) The Cyrene member, which will include the lower, fossiliferous limestone phase of the formation below the Bowling Green member, exposed 1 to 2 miles east of Cyrene and Edgewood, in Pike County, Missouri, and about 2 miles north of Thebes, in Alexander County, Illinois; (2) the Noix oolite member, which will refer to the local oolite facies of the formation, which is the equivalent of a variable portion of the upper part of the Cyrene member; and (3) the Bowling Green member, which will embrace the buff or brown, mostly unfossiliferous, limestone in the upper part of the formation, corresponding to the strata outcropping near Bowling Green, Missouri.

The name Channahon limestone will be retained for easy reference to the strata seen only along the Desplaines River 1 mile southeast of Channahon, in Will County, Illinois. This limestone is considered the equivalent of some part of the Edgewood formation, but it can not yet be correlated with any particular part of this formation because of the complete isolation of the area from other exposures of the Edgewood limestone and the slight difference in its fauna from that of the typical Edgewood limestone in eastern Missouri and southwest Illinois.

Strata representing parts of the Edgewood limestone are nearly coextensive with the distribution of the Alexandrian series in the States of Illinois and Missouri. The lower, fossiliferous layers of the formation (Cyrene member) are present near the river in Alexander County, Illinois, and over a considerable area in the vicinity of Edgewood and Cyrene, in Pike County, Missouri, where they are in places overlain by the Bowling Green member. Farther north, near Bowling Green and McCune Station, the Cyrene member of the Edgewood is mostly absent and the overlying Bowling Green member makes up the greater part of the formation.

Detailed sections.—An excellent exposure of the lower strata of the Edgewood limestone appears in Illinois along the east bank of the Mississippi River, about 1½ miles north of Thebes, where they occur in the bottom of a low syncline and occupy an old channel eroded in the Girardeau limestone during the post-Girardeau–pre-Edgewood land interval. The succession of strata at this place is shown in the following detailed section:

Section exposed along the River 1½ Miles North of Thebes

		Feet	In.
4–10.	Edgewood formation (Cyrene member).		
10.	Heavy layer of gray, coarsely granular limestone, oolitic in the upper part, containing *Lyellia thebesensis*, *Rhynchotreta thebesensis*, *Whitfieldella billingsana*, *Metapolichas breviceps* var. *clintonensis*, and other fossils	3	6
9.	Rather soft, gray shale, without fossils	1	2
8.	Dark gray, argillaceous limestone or calcareous shale, in two layers each about 6 inches thick, separated by a 2-inch parting of softer shale; the calcareous layers contain the fossils *Schuchertella propinqua*, *Whitfieldella ovoides*, and *Dalmanites danai*	1	3
7.	Rather soft, gray shale, without fossils	1	6
6.	Layer of somewhat fissile, fine-grained, argillaceous limestone containing few fossils	1	6
5.	Layer of rather hard limestone having a 2-inch band of chert at the top; no fossils found	..	8
4.	Layer of conglomerate consisting of fragments of Girardeau limestone from 2 to 12 inches in diameter embedded in a matrix of fine-grained limestone; in some places this member appears to be composed of calcareous concretions surrounded by softer, bluish-gray shale	2	6
	A break in deposition.		
3.	Girardeau limestone: Hard, fine-grained, brittle, dark colored limestone, with fossils characteristic of the Girardeau formation	2	6
	A break in deposition.		
2.	Orchard Creek shale (Richmond): Bluish-gray, calcareous shale, containing 1- to 2-inch bands of shaly, concretionary limestone, 4 to 6 inches apart	18	..
	A break in deposition.		
1.	Thebes sandstone: Brown or chocolate colored, rather fine-grained sandstone, which weathers into thin layers	40	..

In the above section the members 4 to 10, inclusive, constitute the Edgewood beds, as that formation is seen at its best exposure in southwest Illinois. At this place the Girardeau limestone was almost entirely cut out by erosion prior to the deposition of the Edgewood strata. A thickness of 13 or more feet of the Girardeau limestone outcrops in the river bluff a few rods north of this place, and masses of this rock, 6 or 8 feet in thickness, are also exposed along the river bank a few rods south of the place where the section was made. The conglomerate at the base of the Edgewood, number 4 in the section, is largely composed of fragments of Girardeau limeston.

Another instructive exposure of the Edgewood strata in this vicinity is in an abandoned quarry one-fourth mile southeast of the village of Gale, about 2 miles northeast of Thebes. This is in the northeast quarter of section 4, township 15 south, range 3 west, where the following section was made:

Section in abandoned Quarry One-fourth Mile Southeast of Gale

	Feet	In.
4. Sexton Creek (=Brassfield) limestone: Hard, gray limestone, in layers 4 to 8 inches thick, which are separated one from another by 2- to 3-inch chert bands	11	..
A break in sedimentation.		
3. Edgewood formation (Cyrene member): Single layer of gray, somewhat oolitic limestone, containing small pebbles of chert ¼ inch to 4 inches in diameter	..	10
A break in sedimentation.		
2. Orchard Creek shale: Bluish-gray calcareous shale bearing 1- to 2-inch bands of impure, concretionary limestone 4 to 6 inches apart	8	..
A break in sedimentation.		
1. Thebes sandstone: Brown, fine-grained, slightly shaly sandstone, at the top of which is a hard, deeply iron-stained zone	6	..

In the section given above the single layer comprising the third member represents the total thickness of the Edgewood formation at this place. It probably belongs to a level a little higher than that of the uppermost layer in the preceding section.

Strata equivalent to those of the Edgewood limestone near Thebes, Illinois, are well developed in the vicinity of Edgewood, in Pike County, Missouri. Along the streams 1 to 1½ miles east and northeast of this town the following strata are exposed:

Section of Strata 1½ Miles Northeast of Edgewood, Missouri

	Feet
2, 3. Edgewood limestone.	
3. Brown to yellow limestone, with few or no fossils (Bowling Green limestone member)	22
2. Brown limestone, in layers 2 to 6 inches thick, with *Schuchertella propinqua* and *Dalmanites danai* common in lower part, and *Atrypa præmarginalis*, *A. putilla*, and *Dalmanella edgewoodensis* abundant in the upper; containing the greater number of the fossils indicated in column number 2 of the table on page 365 (Cyrene member)	6–11
A break in sedimentation.	
1. Orchard Creek shale: Bluish-gray shale, with *Strophomena rugosa*, *Isotelus* sp., and other fossils	9–14

In a few places in this vicinity the limestone corresponding to number 2 in the foregoing section (Cyrene member) is light gray, but usually its color is brown. The upper 1 or 2 feet of this limestone, immediately below the Bowling Green member, contains a somewhat different fauna in different localities.

In some places, as southeast of Edgewood, south of Clarksville, and at Louisiana, the upper layer contains many corals, including *Calapœcia favositoidea, Clathrodictyon vesiculosum, Favosites subelongus, Lyellia thebesensis,* and *Zaphrentis subregularis,* together with the form of *Platystrophia* described by Foerste as *P. daytonensis, Whitfieldella ovoides,* and *Cyclonema daytonensis.* In other places the corals are mostly absent from this layer, and its fauna consists largely of species of Atrypa, Camarotœchia ? and Dalmanella.

A few miles north of Edgewood, between Bowling Green and Watson Station, and still farther north in the vicinity of McCune Station, the Edgewood limestone is represented by 25 to 35 feet by brown, nonfossiliferous limestone (Bowling Green member), at the base of which is a band 1½ to 2 feet thick, containing numerous shells of *Atrypa præmarginalis, A. putilla, Camarotœchia ? concinna,* and *Dalmanella edgewoodensis.* This lower fossiliferous band corresponds to only the upper part of the Cyrene member in the section northeast of Edgewood.

Deposition of the Bowling Green limestone member is thought to have been initiated by a slight uplift of the region bordering the west side of this basin in Lincoln, Pike, and Ralls counties, Missouri, accompanied by a slight subsidence of the area east of the line of uplift. Sedimentation appears generally to have been uninterrupted from the top of the fossiliferous part of the Edgewood into the Bowling Green member. This movement put a stop to oolite deposition, and so quickened erosion of the land on the west as to increase the discharge of mechanical sediments into the basin, the Bowling Green limestone consisting of 15 to 25 per cent of very fine sand.

Three to 6 miles west of Mississippi River the limestone, equivalent to the upper layers of the Cyrene member near Edgewood, passes with a gradual transition into a thin bed of gray oolite which thickens towards the east, attaining its maximum in the vicinity of Louisiana, Missouri. A variable thickness of brown Bowling Green limestone usually overlies the oolite, being thickest where the oolite is thinnest and thinnest where the oolite is best developed. The oolite bed does not increase in thickness at the expense of the lower part of the Bowling Green limestone, but where the oolite is thickest there is represented a greater thickness of the upper part of the Cyrene limestone member.

There is given below a section of the strata exposed in the south bank of Noix Creek, at Louisiana, Missouri, where the oolite bed has its greatest known development:

Section along Noix Creek at Louisiana, Missouri

	Feet
3. Upper Devonian shale: Dark colored fissile shale, with few fossils....	3
A break in sedimentation.	
2. Edgewood limestone (Noix oolite): Light gray oolite, in three layers, containing the greater number of the fossils indicated in column 3 of the table on page 365..	8
A break in sedimentation.	
1. Orchard Creek shale: Bluish to greenish-gray shale, with few or no fossils..	9

The Bowling Green limestone is absent at the place where the above section was made, but 2 to 4 feet of this limestone is present above the oolite less than 1 mile west, and 6 to 8 feet of the Bowling Green limestone overlies the oolite at the mouth of Buffalo Creek, 1½ miles southeast of Louisiana.

As is common with oolite faunas, the shells in the oolite at Louisiana are usually distinctly smaller than those of corresponding species from the limestone that is not oolitic. They are often so silicified that perfect specimens of even the smallest forms can be obtained by dissolving the limestone with weak acid. The fossils from the oolite at Louisiana are indicated by a cross to the right of the name, in column 3 of the table given below. A cross opposite the name in column 2 of the table shows that the species was found in the Edgewood limestone near Edgewood, Missouri, while a cross opposite the name in column 1 indicates the presence of that species in the Edgewood limestone near Thebes, Illinois.

Comparative Table of Fossils from the Edgewood Limestone

Localities: Column 1, near Thebes, Illinois; column 2, near Edgewood, Missouri; column 3, Noix oolite near Louisiana, Missouri

	(1)	(2)	(3)
Calapœcia favositoidea Savage........................	×	×	×
Calvinia edgewoodensis Savage........................	×	..	..
Clathrodictyon vesiculosum Nicholsen and Murie............	×	×	×
Favosites subelongus Savage........................	×	×	×
Halysites catenulatus Linnæus........................	..	..	×
Lyellia thebesensis Foerste........................	×	×	×
Zaphrentis cf. *ambigua* Savage........................	×	×	×
Zaphrentis subregularis Savage........................	×	×	×
Zaphrentis cf. *stokesi* Edwards and Haime................	×	×	×
Atrypa præmarginalis (Savage)........................	×	×	×
Atrypa putilla (Hall and Clarke)........................	×	×	×
Atrypa tubulistriata Savage........................	×	×	×
Brachyprion stropheodontoides Savage....................	..	..	×
Brachyprion latisculptilis Savage........................	..	×	×

	(1)	(2)	(3)
Camarotœchia? antiqua Savage	×	×	..
Camarotœchia? concinna Savage	×	×	×
Clorinda? thebesensis Savage	?	×	..
Dalmanella edgewoodensis Savage	×	×	×
Hindella? ambigua Savage	×	×	..
Homœospira fiscellostriata Savage	..	..	×
Homœospira subcircularis Savage	..	×	×
Leptœna rhomboidalis (Wilckens)	×	×	×
Orthis flabellitis var. *fissiplicata* Foerste	..	..	×
Pentamerus parvulus Savage	..	..	×
Platystrophia daytonensis Foerste	×	×	×
Protozeuga sulcocarinata Savage	..	..	×
Rafinesquina? mesicosta (Shumard)	×	×	×
Refinesquina? mesicosta var. *mesistria* Savage	..	..	×
Rhipidomella tenuilineata Savage	..	..	×
Rhynchonella? janea Billings	×	×	..
Rhynchotreta parva Savage	×	×	×
Rhynchotreta thebesensis Foerste	×	×	×
Rhynchotreta thebesensis var. *multistriata* Savage	×	..	..
Schuchertella cf. *missouriensis* (Shumard)	..	..	×
Schuchertella missouriensis var. *convexa* Savage	..	..	×
Schuchertella propinqua (Meek and Worthen)	×	×	×
Spirifer (*Delthyris*) sp.	×	..	..
Whitfieldella billingsana (M. and W.)	×	×	..
Whitfieldella ovoides Savage	×	×	×
Whitfieldella speciosa Savage	×	×	×
Bellerophon consimilis Savage	×	×	..
Bellerophon cf. *exiguus* Foerste	×	×	×
Bucania sp	..	..	×
Cyclonema daytonensis Foerste	×	×	×
Diaphorostoma niagarensis (Hall)	×	×	×
Holopea minuta Savage	..	×	..
Hormotoma tenera Savage	×	×	×
Liospira cf. *affine* Foerste	..	..	×
Lophospira fasciata Savage	..	×	×
Lophospira thebesensis Savage	×	..	×
Poleumita bellasculptilis Savage	..	×	..
Straparollus pumilis Savage	..	×	..
Colpomya abrupta Savage	..	×	×
Ctenodonata subelliptica Savage	..	×	..
Cypricardinia subquadrata Savage	..	..	×
Pterinea thebesensis Meek and Worthen	×	×	×
Dawsonoceras cf. *tenuilineatum* Savage	..	×	..
Cyphaspis intermedia Weller	×	×	×
Dalmanites danai Meek and Worthen	×	×	?
Isotelus longævus Savage	..	×	..
Metapolichas breviceps var. *clintonensis* Foerste	×	×	×
Proetus determinatus Foerste	×	×	×

The close similarity of the fossils from the different Edgewood localities compared in the above table leaves no doubt of the general equivalence of the strata from which they came. The oolite bed at Louisiana (Noix oolite member) is equivalent to about the upper two-thirds of the Cyrene member of the Edgewood limestone as developed near Thebes, Illinois, and east of Edgewood, Missouri.

East of Louisiana the oolite bed becomes thinner, so that where it appears in the Mississippi bluff on the Illinois side of the river, 10 miles east of Louisiana, a thickness of about 3 feet is present. In these more easterly exposures of the bed, in Pike and Calhoun counties, Illinois, the lower part of the oolite present at Louisiana, Missouri, is absent and the bed is overlain by 12 to 16 feet of brown Bowling Green limestone, which is in turn followed by the Sexton Creek (Brassfield) limestone.

Near the south margin of the area of outcrop of the Alexandrian strata in northeast Illinois, in the east bank of the Kankakee River, 3½ miles below Custer Park, there is exposed a bed of iron-stained oolite 3½ feet thick, which is thought to be the equivalent of the Noix oolite in Missouri and western Illinois. It rests on Maquoketa shale and is succeeded by 6 to 9 feet of brown limestone, resembling the Bowling Green member, which is in turn followed by the Sexton Creek (Brassfield) limestone.

The oolite development appears to be restricted to the north and east parts of the area of the Edgewood limestone bordering the Mississippi River and to the south side of the area of Alexandrian rocks in northeastern Illinois.

The Channahon limestone member.—In the northeast Illinois area the Channahon limestone member of the Edgewood limestone is exposed along the south bank of Des plaines River, about 1 mile southeast of the village of Channahon, in Will County. This limestone also underlies the surficial materials over a limited area on the north side of the river. A section of strata exposed at the former locality is as follows:

Section of Channahon Limestone near Channahon, Illinois

	Feet	In.
3. Dark gray to brown, rather fine-grained, impure limestone in layers 3 to 6 inches thick, containing many fossils.............	1	6
2. Dark colored limestone, consisting of a fine-grained matrix in which are embedded numerous simple corals, besides *Leptæna rhomboidalis, Schuchertella curvistriata, Pterinea elegans, Metapolichas ferrisi*, and other fossils....................................	2	6
1. Fine-grained, yellowish-gray, laminated sandstone, without fossils, to the level of the water in the river.........................	5	..

In the above section there is no apparent unconformity between the different members, although the lithology of the sandstone at the base is markedly different from that of the overlying limestone, and the numerous corals occurring in the second member are absent from the upper bed. The contact of these rocks with the Maquoketa shale below or with Silurian limestone above can not be seen at the place where the section was made. However, early Silurian strata thought to represent some part of the Sexton Creek (Brassfield) limestone are exposed a few rods east of this place at a level only a few feet higher than the top of the uppermost member of the section. A blue plastic shale, that doubtless belongs to the Maquoketa, outcrops in the bank of the river about one-half mile farther east at an altitude slightly above that of the top of the section. In the vicinity of Millsdale, where the contact of the lower layers of Silurian limestone with the underlying Maquoketa shale is well exposed, the Channahon limestone is absent.

The Channahon limestone furnished the fossils listed in the left-hand column below. In the column on the right are given the names of the species from the Edgewood limestone in Missouri and Alexander County, Illinois, that are nearly related to the respective Channahon forms.

Comparative Table of Fossils

Fossils from the Channahon limestone in Will County, Illinois	Fossils from the Edgewood formation in Missouri, and Alexander county, Illinois
Zaphrentis ambigua Savage	*Zaphrentis ambigua* Savage
Zaphrentis subregularis Savage	*Zaphrentis subregularis* Savage
Zaphrentis stokesi Edwards and Haime ?	*Zaphrentis stokesi* Edwards and Haime
Atrypa ? sp.	*Atrypa putilla* (Hall and Clarke)
Dalmanella elegantula var.	*Dalmanella edgewoodensis* Savage
Leptæna rhomboidalis (Wilckens)	*Leptæna rhomboidalis* (Wilckens)
Lingulops illinoisensis Savage	
Pholidops subelliptica Savage	
Rhipidomella hybrida (Sowerby)	
Rhynchotreta lepida Savage	*Rhynchotreta parva* Savage
Rhynchotreta intermedia Savage	*Rhynchotreta thebesensis* Foerste
Schuchertella curvistriata Savage	*Schuchertella propinqua* (M. and W.)
Whitfieldella acuminata Savage	*Whitfieldella billingsana* (M. and W.)
Whitfieldella ovoides Savage	*Whitfieldella ovoides* Savage
Callonema pristina Savage	
Cyclonema daytonensis Foerste	*Cyclonema daytonensis* Foerste
Diaphorostoma illinoisensis Savage	*Diaphorostoma niagarensis* Hall
Pterinea elegans Savage	*Pterinea thebesensis* M. and W.
Dawsonoceras tenuilineatum Savage	*Dawsonoceras* cf. *tenuilineatum* Savage
Cyphaspis intermedia Weller	*Cyphaspis intermedia* Weller
Metapolichas ferrisi Weller	*Metapolichas breviceps* var. *clintonensis* Foerste
Proetus channahonensis Weller	*Proetus determinatus* Foerste
Leperditia illinoisensis Savage	

While the correspondence of the respective species of fossils compared from the two areas is not identical, yet the differences between many of them are slight. The fauna of the Channahon limestone is more closely related to that of the Edgewood formation than to any other known fauna.

It is thought that the strata in the two areas represent about the same period of deposition, and that the differences in the fossils are largely due to local differences in the marine environments of the faunas in the respective regions.

THE ESSEX LIMESTONE

Occurrence and relation to other strata.—The Essex limestone includes the strata outcropping along Horse Creek, 1½ miles east of the town of Essex, in Kankakee County, Illinois. It occupies a position above the Edgewood limestone and below the Sexton Creek (Brassfield) limestone.

Detailed section.—The character of the Essex limestone is shown in the following detailed section:

Section of Essex Limestone near Essex, Illinois

	Feet
3. Sexton Creek (Brassfield) limestone: Yellowish-brown, much weathered masses of magnesian limestone containing nodules and masses of chert bearing *Pentamerella ? manniensis* and other fossils........	3½
1, 2. Essex limestone.	
2. Yellowish-brown, thin bedded, magnesian limestone, in layers 3 to 5 inches thick, with numerous fossils................................	8½
1. Rather hard, bluish colored, shaly limestone, in layers 2 to 6 inches thick, exposed above the level of low water........................	2

The contact between the members 2 and 3 in the above section is not so clearly exposed that the presence or absence of a depositional hiatus between them could be certainly determined. Farther south, in Pike County, Missouri, and Calhoun County, Illinois, *Pentamerella ? manniensis* is a guide to the basal layers of the Sexton Creek (Brassfield) limestone. Hence the upper limestone, number 3 of the section, is referred to the Sexton Creek formation. The fauna of the Essex limestone, numbers 1 and 2 of the section, has not been recognized farther south in Illinois and Missouri, where this limestone has probably been cut out by pre-Brassfield erosion. The species are listed below:

Fossils from the Essex Limestone[25]

Favosites cf. *niagarensis* Hall
Halysites catenulatus Linn
Zaphrentis sp.
Rhynchotreta thebesensis Foerste
Schuchertella sp.
Schuchertella cf. *subplana* (Conrad)

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[25] The species of fossils from the Essex and the Sexton Creek limestones will be figured and described in a later paper dealing with the stratigraphy and paleontology of these formations, now in preparation.

Atrypa marginalis (Dalman)
Atrypa putilla (Hall and Clarke)
Atrypa sp.
Camarotœchia near *acinus* Hall
Camarotœchia ? cliftonensis Foerste
Dalmanella elegantula var.
Gypidula sp.
Leptæna rhomboidalis (Wilckens)

Rhipidomella hybrida (Sowerby)
Rhynchotreta lepida Savage
Rhynchotreta simplex Foerste
Strophonella sp.
Whitfieldella cf. *cylindrica* Hall
Whitfieldella sp.
Bellerophon sp.
cf. *Cyclora alta*
Conularia sp.
Diaphorostoma sp.
Pleurotomaria sp.
Loxonema sp.
Mytilarca cf. *mytiliformis* (Hall)
Modiolopsis sp.
Pterinea sp.

Of the fossils of the Essex limestone, *Atrypa putilla* and *Rhynchotreta thebesensis* are common Edgewood species that are not known in the higher Sexton Creek (Brassfield) limestone. Abundant also in the Essex limestone are *Camarotœchia ? cliftonensis, Rhynchotreta simplex*, and other species that have not been found in the Edgewood limestone of Missouri and Illinois, but which occur in, or more probably immediately below, a limestone containing Brassfield fossils in western Tennessee.

The strata below number 1 of the section could not be seen at this place, and 60 rods farther down the creek a thickness of 14 feet of Maquoketa shale is exposed with no overlying limestone.

The Essex limestone is thought to represent a distinct formation, although its contact with the overlying Sexton Creek limestone is not clearly exposed. Later studies may show that it should be regarded as a member of the latter formation. It occurs below the *Pentamerella ? manniensis* horizon, which farther south in Illinois and Missouri marks the basal layers of the Sexton Creek limestone, and are separated from the Bowling Green member of the Edgewood limestone by a sedimentary break. The Essex limestone is thus seen to be younger than the uppermost Edgewood strata and older than the basal layers (containing *Pentamerella ? manniensis*) of the Sexton Creek limestone of Missouri and Illinois.

THE SEXTON CREEK (BRASSFIELD) LIMESTONE

Occurrence and relation to other strata.—The name Sexton Creek limestone was taken from Sexton Creek, in northwest Alexander County, Illinois, along which stream these rocks are well developed and exposed. These strata, which are considered the equivalent in time of some part of the Brassfield east of the Cincinnati axis, overlap the Edgewood limestone on the east and north in the Mississippi River region and in the south and east in northeast Illinois. They probably transgressed the Edgewood strata over all the area of its distribution, but on account of greater uplift along the west part of the Mississippi River area in post-

Sexton Creek time these strata have been denuded from a considerable part of eastern Missouri.

Detailed sections.—The lower layers of the Sexton Creek limestone, containing *Pentamerella ? manniensis,* are present south of Clarksville, in Pike County, Missouri, and across the Mississippi River near Belleview, Illinois. The Sexton Creek limestone is well developed in Calhoun and Pike counties, Illinois, as shown in the following section of strata exposed in the vicinity of Hamburg and Pleasant Hill:

Section of Strata in the Vicinity of Hamburg, Illinois

		Feet
5.	Middle Devonian (Iowa Hamilton) limestone: Coarse-grained, gray limestone, containing *Spirifer iowensis* and other fossils of the Iowa Hamilton	4
	A long break in deposition.	
4.	Sexton Creek (Brassfield) limestone: Hard, gray limestone in layers 6 to 30 inches thick, containing the greater number of fossils listed in column number 1 of the table on page 372.	48
	A break in deposition.	
2, 3.	Edgewood limestone:	
3.	Yellow to brown limestone which on weathering breaks into thin slabs in an almost vertical direction; fossils few (Bowling Green member)	16
2.	Light gray oolite containing fossils similar to those in the middle parts of the oolite at Louisiana, Missouri (Noix oolite member)	3½
	A break in deposition.	
1.	Maquoketa or Orchard Creek shale: Bluish, plastic shale, without fossils, exposed	7

The basal layers of the Sexton Creek limestone in this region, both in Missouri and Illinois, are marked by numerous shells of *Pentamerella ? manniensis* Foerste and a species of Pentamerus. A narrow zone, 18 to 20 feet below the top of the formation, contains *Rhinopora* near *verrucosa, Stricklandinia triplesiana, Stricklandinia* n. sp., and *Triplecia ortoni.* The upper 10 feet of this limestone furnished *Syringolites* cf. *huronensis* and *Spirifer radiatus.* The fauna of the Sexton Creek limestone in this vicinity is shown in the table of fossils on a later page.

In northeast Illinois the Sexton Creek limestone is thought to be present over a considerable area in Will and Kankakee counties. A succession of strata very similar to that described in the last section occurs along the east bank of Kankakee River, 3 to 4 miles below Custer Park, in Will County, as shown in the section given below:

Section of Strata along Kankakee River, below Custer Park

		Feet
4.	Sexton Creek (Brassfield) limestone: Hard, gray, rather massive limestone, containing many fossils at certain levels	18–28
	A probable break in deposition.	

	Feet
2, 3. Edgewood limestone ?	
3. Yellow to brown, earthy limestone, with few or no fossils......	4½
2. Reddish-brown, iron-stained oolite (Noix oolite member ?)......	3¾
A break in sedimentation.	
1. Maquoketa shale: Bluish-gray, plastic shale, with no fossils.....	4–8

In the upper part of the Sexton Creek limestone exposed at this place is a layer containing *Clathropora* cf. *frondosa, Rhinopora* near *verrucosa, Stricklandinia triplesiana, Stricklandinia* n. sp., and *Triplecia ortoni,* which corresponds to the layer containing similar fossils, and occurring 18 to 20 feet below the top of the Sexton Creek limestone in the vicinity of Hamburg.

In the following table of fossils a cross in column 1 opposite the name indicates that the species was found in the Sexton Creek limestone in the vicinity of Hamburg and Pleasant Hill, while a corresponding cross in column 2 shows that the species was obtained from the Sexton Creek limestone below Custer Park:

Fossils from the Sexton Creek Limestone

	Near Hamburg and Pleasant Hill (1)	Near Custer Park, Illinois (2)
Clathrodictyon vesiculosum Nich. and Murie..............	×	×
Diphyphyllum cæspitosum Hall.........................	..	×
Favosites favosus Goldfuss..........................	×	×
Halysites catenulatus Linnæus........................	×	×
Lyellia sp..	×	×
Syringolites cf. *huronensis* Hinde......................	×	×
Syringopora sp......................................	×	×
Syringostroma sp....................................	×	×
Thecia sp...	×	×
Zaphrentis sp.......................................	×	×
Callopora sp..	×	×
Clathropora cf. *frondosa* Hall........................	..	×
Rhinopora near *verrucosa* Hall.........................	×	×
Rhinopora sp..	×	..
Atrypa marginalis (Dalman)...........................	×	×
Atrypa reticularis (Linnæus)..........................	×	×
Camarotœchia acinus var. *convexa* Foerste...............	×	..
Camarotœchia sp.....................................	×	..
Clorinda ? sp..	×	×
Dalmanella elegantula (Dalman)........................	×	×
Dalmanella sp.......................................	×	×
Leptæna rhmboidalis (Wilckens).........................	×	×
Orthis flabellites Foerste.............................	×	×
Pentamerus oblongus Sowerby..........................	×	×
Pentamerus sp.......................................	×	×
Platystrophia daytonensis Foerste......................	×	..

	(1)	(2)
Platystrophia reversata Foerste	×	×
Plectambonites cf. *transversalis* var. *elegantula* Foerste	×	×
Schuchertella sp.	..	×
Spirifer radiatus Sowerby	×	..
Stricklandinia triplesiana Foerste	×	×
Stricklandinia sp.	×	×
Stropheodonta sp.	×	..
Strophonella filistriata Foerste	×	×
Strophonella cf. *roemeri* Foerste	×	..
Triplecia ortoni Meek	×	×
Whitfieldella sp.	×	..
Diaphorostoma niagarense (Hall)	×	×
Amphicœlia cf. *leidyi* Hall	×	..
Dawsonoceras sp.	×	..
Orthoceras sp.	×	×
Bronteus acamus Hall	×	×
Ceraurus cf. *niagarensis* Hall	×	×
Encrinurus sp.	×	×
Illænus ambiguus Foerste	×	×
Illænus cf. *daytonensis* Foerste	×	..
Illænus madisonianus Whitfield	×	×
Illænus sp.	×	×

In the above list the greater number of fossils to which no specific names are given are new. The similarity of the faunas of the Sexton Creek limestone in the vicinity of Hamburg and below Custer Park along the Kankakee River indicates that the strata at the two localities are equivalent.

The presence in the Sexton Creek limestone of such characteristic Brassfield species as *Clathropora* cf. *frondosa, Rhinopora* near *verrucosa, Camarotœchia acinus* var. *convexa, Strophonella filistriata, Stricklandinia triplesiana* and *Tripecia ortoni* indicates that the Sexton Creek limestone in the Mississippi Valley represents about the same general period of deposition as the Brassfield limestone, east of the Cincinnati axis, in Ohio.

GENERAL CONCLUSIONS

It should be noted that the fauna of the Sexton Creek limestone in the Mississippi Valley lacks several species that are present in the Brassfield limestone in Ohio, such as *Pachydictya bifurcata, Phænopora magna, Camarotœchia ? scobina, Dalmanites werthneri,* and *Cyphaspis clintonensis.* A number of fossils not found in the Brassfield limestone east of the Cincinnati anticline are present in the Sexton Creek limestone of Illinois and Missouri, among which are *Callopora* n. sp., *Rhinopora* n. sp., *Pentamerus oblongus, Spirifer radiatus, Stricklandinia* n. sp., *Amphicœlia* cf. *leidyi,* and *Bronteus acamus.*

Although the basin in which the Sexton Creek limestone of the Mississippi Valley region and the Brassfield limestone of the Ohio region are both thought to have had a southward sea connection, the difference in the faunas of this time in the two areas is interpreted as indicating the presence between them of a land barrier (the enlarged Cincinnati anticline), extending sufficiently far to the south to prevent the easy migration of the organisms into this localized basin, in which there developed a somewhat provincial fauna.

For this basin connecting southward with the wider sea of the Tennessee and Arkansas region, in which the Alexandrian strata in Illinois and Missouri were laid down, the name Illinois basin is here proposed. This basin is thought to have been a northwardly extending embayment and a distinct area of sedimentation during the time of deposition of all of the strata in this region from the beginning of the Thebes sandstone to the end of the Sexton Creek limestone.

During Alexandrian time the Illinois basin had a widely open typically marine southern connection with the Gulf region, and from the Tennessee area another bay, known as the Brassfield, extended widely east of the Cincinnati axis, in Ohio and Kentucky. The early Silurian sea gained access to the Illinois and Missouri region earlier, and probably continued later, than in the region east of the Cincinnati axis. Several of the genera and a number of the species of fossils that occur in the Brassfield limestone in Ohio were introduced a little earlier into the Illinois basin, appearing in late Edgewood strata. In the upper part of the Sexton Creek limestone there are a few species that do not appear east of the Cincinnati axis until post-Brassfield time.

In the fauna of the Edgewood limestone there can be recognized an element that was derived from that of the Girardeau limestone, and in the Sexton Creek fauna there appears a still larger element that was present in the earlier Edgewood limestone. The Alexandrian series in the Illinois basin is thus shown to consist of a number of closely related early Silurian formations which record a succession of oscillatory northward sea advances that are seemingly separated one from another by sedimentary breaks due to temporary sea withdrawal. The earliest of these invasions, represented by the Girardeau limestone, was the least extensive. The deposits of each succeeding invasion reached farther north and were spread more widely than those of the preceding, the cycle of early Silurian sedimentation in this region culminating in the Sexton Creek submergence.

The relations of the Alexandrian formations above described are shown in the following composite section:

GENERALIZED SECTION OF THE ALEXANDRIAN STRATA IN MISSOURI AND ILLINOIS

System	Series	Formations	Location of exposures	Description of horizons	Feet
SILURIAN	Niagaran	Clinton (of New York)			
				A break in sedimentation.	
	ALEXANDRIAN	SEXTON CREEK (Brassfield) limestone, 48 to 70 feet	Alexander County, Ill., N. W. ¼ Sec. 27, T. 14 S., R. 3 W. Calhoun County, Ill., S. part of Hamburg.	4*c*. Light gray, hard, thick-bedded limestone, with *Syringolites* cf. *huronensis* and *Spirifer radiatus*, 10 feet in Calhoun and Pike counties. Pink limestone, 23 feet, in Alexander County, Illinois..........................	10 to 23
			Alexander County, Ill., N. W. ¼ Sec. 27, T. 14 S., R. 3 W. Calhoun County, Ill., S. part of Hamburg and ¼ mile N. of Hardin. Pike County, Ill., 3½ miles N. of Pleasant Hill. Will County, Ill., 4 miles S. E. of Custer Park.	4*b*. Light gray, hard limestone; fossils numerous in certain layers. *Rhinopora* near *verrucosa*, *Camarotœchia acinus* var. *convexa*, *Strophonella filistriata*, *Stricklandinia triplesiana*, *Stricklandinia* n. sp., and *Triplecia ortoni* common about 10 feet below the top, about	34
			Pike County, Mo., ⅓ mile N. of Kissenger. Calhoun County, Ill., S. part of Belleview. Jersey County, Ill., 2 miles W. of Grafton. Kankakee County, Ill., 1½ miles E. of Essex.	4*a*. Light gray limestone containing *Pentamerella ? manniensis* and *Pentamerus* sp................	1½
				A possible break in the deposition.	

System	Series	Formations	Location of exposures	Description of horizons	Feet
SILURIAN	ALEXANDRIAN	Essex limestone, 10 to 12 feet	Kankakee County, Ill., 1½ miles E. of Essex.	3*a*. Yellowish brown magnesian limestone above, bluish shaly limestone below, in layers 3 to 9 inches thick. *Atrypa putilla*, *Camarotœchia? cliftonensis*, *Rhynchotreta simplex*, *R. thebesensis*, *Schuchertella* cf. *subplana*, and other fossils..................	10½
				A break in deposition.	
		Edgewood limestone, 12 to 50 feet	Pike County, Mo., near McCune Station, between Watson Station and Bowling Green, 3½ miles S. of Clarksville. Calhoun County, Ill., 3½ miles S. of Hamburg. Pike County, Ill., 2 miles N. of Pleasant Hill.	2*b*. Bluish to brown impure limestone in layers 3 to 36 inches thick, with few fossils (Bowling Green member)..................	15 to 35
			Alexander County, Ill., 1½ miles N. of Thebes. Pike County, Mo., 1½ miles E and N. E. of Edgewood and at Louisiana. Will County, Ill., 1 mile S. E. of Channahon. Calhoun County, Ill., 3½ miles S. of Hamburg.	2*a*. Gray to brown limestone, the upper layer in places containing *Calapœcia favositoidea*, *Favosites subelongus*, *Whitfieldella oroides*, and *Cyclonema daytonensis*. Below this *Atrypa præmarginalis*, *A. putilla*, *Camarotœchia? concinna*, *Dalmanella edgewoodensis*, and *Whitfieldella billingsana* are common. The lower layers with *Dalmanites danai* and *Schuchertella propinqua* common (Cyrene member)........... The upper one-half to two-thirds of this member is oolitic (Noix oolite) near the Mississippi River.	8 to 15
				A break in sedimentation.	
		Girardeau limestone, 33 to 38 feet	Alexander County, Ill., 1½ miles N. of Thebes and 2½ miles S. of Thebes. Cape Girardeau County, Mo., 1½ miles N. of Cape Girardeau.	1. Fine-grained, dark limestone, in layers 1 to 5 inches thick, with *Ptychocrinus splendens*, *Rafinesquina? mesicosta*, *Schuchertella missouriensis*, *Protozeuga sulcocarinata*, and *Cornulites incurvus*,	33 to 38
		A break in sedimentation.			
Ordovician	Cincinnatian	Richmond or Maquoketa			

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CORRELATION PROBLEMS SUGGESTED BY A STUDY OF THE FAUNAS OF THE EASTPORT QUADRANGLE, MAINE[1]

BY HENRY SHALER WILLIAMS

(*Read before the Society December 28, 1912*)

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PART I. THE FACTS

INTRODUCTORY

At the last meeting of the Society I read a brief paper setting forth the general correlations of the several faunas of the Eastport quadrangle.[2]

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[1] Published by permission of the Director of the United States Geological Survey. Manuscript received by the Secretary of the Society January 15, 1913.

[2] Correlations of the Paleozoic faunas of the Eastport quadrangle, Maine. Bull. Geol. Soc. America, vol. 23, 1911, pp. 349-356. July 15, 1912.

During the past year Mr. E. S. Bastin has been preparing the maps for the folio and I have been at work on the fossils. The folio is now ready for publication. In the paper above referred to I designated the several faunas by numbers. Names have now been agreed on for the several formations from which the faunas were derived to be used in the folio as follows:

Fauna number I is from the Quoddy shale of the folio. (Bottom.)

Fauna number II is from the Dennys formation.

Fauna number III is from the Edmunds formation.

Fauna number IV is from the Pembroke formation.

Fauna number V is from the Eastport formation.

Fauna number VI is from the Perry formation (already named by Smith and White). (Top.)

Briefly stated, the first five of these formations belong to the Silurian system of the New York section,[3] and the sixth (Perry formation), separated by unconformity from those below, is correlated with the Catskill and Chemung of the Upper Devonian.[4]

To indicate the correlations more specifically, I have prepared a chart which expresses the relations I think the faunas of the Eastport quadrangle bear to the New York and English sections as classified. The position of the names and the cross-lines will indicate what I regard the relations to be. Thus I regard the Pembroke and Eastport to be successive faunas representing the English Upper Ludlow and Downtonian. The Pembroke is probably not older than the Rondout, but the fauna is not represented definitely in the New York section, and the Eastport is certainly distinct from anything reported either in Silurian or Devonian of New York.

The Edmunds is closely related to the Dennys fauna and their order of sequence is as shown on the chart. I think the Edmunds fauna represents the English faunas from the Wenlock shale to the Aymestry, inclusive, but shows closest affinities with the Wenlock limestone and shale. It is apparently not expressed in the New York section, but its affinities there are almost as close with the Cobleskill as with the Rochester; hence I think it represents the formations from the Rochester to the Cobleskill, inclusive.

The Quoddy is older than the Dennys; it is an entirely different fauna from the Oswegan and it is Silurian and not Ordovician; hence I place it at the bottom of the Silurian; it is evidently Lower Wenlockian. It bears affinities with the New York Niagaran, and that is about as much as can be affirmed at present as to its relations.

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[3] Hartnagel: Classification of the geologic formations of the State of New York. New York State Museum, Handbook 19, April, 1912, table 2.

[4] Smith and White: Geology of the Perry Basin in southeastern Maine. U. S. Geological Survey, Professional Paper No. 35, 1905, p. 83.

	New York (after Hartnagel, 1912)		*Maine* (H. S. Williams, 1912)	*England* (after R. Etheridge, 1888)	
Devonian	Chemung and Catskill		Perry	Devonian or old red sandstone	
	× × × × × × × × × × × × × × ×		(Absent)		
Silurian			Eastport		
	Cayugan	Manlius Rondout Cobleskill Salina	Pembroke	Downtonian or Temeside Upper Ludlow	Ludlow
				Aymestry Lower Ludlow	
	Niagaran	Guelph Lockport Clinton (including Rochester shale at top)	Edmunds Dennys		
	Oswegan	Medina (including Oneida conglomerate) Oswego	Quoddy (not younger than Wenlock shale)	Wenlock limestone Wenlock shales Woolhope Upper Llandovery	Wenlock
Ordovician	Cincinnatian Mohawkian Canadian			Lower Llandovery Caradoc or Bala Llandeilo	

So far, there is little difficulty in establishing the general relationship of the faunas to well known faunas in the formations of New York and other points of the North American continent.

The difficulties arise when the attempt is made to establish precise time-relations between these formations of the Eastport area and those of the New York standards outcropping only a few hundred miles southwest of them.

In order to avoid the vagueness which would result from an attempt to cover the whole series of the faunas of the Eastport quadrangle, I will restrict the present discussion to the details of one of the faunas—that is, the Edmunds—and in giving the facts regarding the Edmunds fauna I will refer only to those species which have, after an exhaustive study of the whole fauna, proven to be of chief significance in solving the problems involved.

In making exact correlations in this part of the geological column, as paleontologists well know, the Brachiopods are more abundantly represented and more frequently met with in various parts of the world, and have been more thoroughly described and illustrated than any other group of organisms. Therefore, when questions of stratigraphic range and geographic distribution are concerned, Brachiopods furnish at least one of the most satisfactory statistics. For this reason I will here confine attention to Brachiopods, simply stating that, so far as the evidence is at hand, the conclusions reached are confirmed by the other classes of invertebrates represented.

GENERAL CORRELATION OF THE EDMUNDS FAUNA

In correlating the fauna of the Edmunds formation I found 21 species, including several classes of invertebrates, identifiable with species already described in literature. Of these 18 are listed in Etheridge's British Paleozoic fossils,[5] and all of them are reported from the Wenlock limestone. All except the coral, *Turbinolopsis bina* Lonsdale, are recorded from the Wenlock shales, and the exception is listed in each of the local divisions of the Wenlock series except the Wenlock shales, and it extends below as far down as the Caradoc and as far up as the Aymestry limestone of the Ludlow.

Three of these do not appear above the Wenlock limestone, namely, *Monomerella woodwardi*, *Rhynchotreta cuneata*, and *Rhynchonella borealis*. Below the Wenlock shales 16 appear in the Woolhope next below and 14 (with one doubtful) in the Upper Llandovery, still lower, and 12 of them appear below the Silurian boundary in the Lower Llandovery, Caradoc, and 4 as low as the Llandeilo.

Above the Wenlock shales 12 appear in the Lower Ludlow, 11 (and one doubtful) in the Aymestry, and 4 in the Upper Ludlow. The evidence thus far seems to warrant the conclusion that the Edmunds fauna is a Wenlock fauna, and is most nearly related to the fauna of the Wenlock limestone and the shales underlying the Wenlock limestone of England.

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[5] R. Etheridge: Fossils of the British Islands, p. 1. Paleozoic, 1888.

NIAGARA GROUP OF HALL AS REPRESENTED IN THE ROCHESTER SHALE OF HARTNAGEL, 1907

Examination of species listed by Hall in 1852 from the Niagara group (Paleontology of New York, volume ii) shows a list of 18 Brachiopods at that time regarded by Hall as either identical or closely related to Wenlock species of the English section. Later investigations have resulted in calling some of them specifically distinct. In the list of species of the fauna of the Rochester shale recently prepared by C. A. Hartnagel, 8 of them are definitely recognized and 3 others are sufficiently close to be regarded for correlation purposes as representatives of the same fauna, namely:

Pholidops squamiformis Hall = *P. imbricata* Sowerby.
Atrypa bidentata Hisinger.
Atrypa plicatella ? Hall = *Rhy. Borealis* Schl. (Davidson).

All of these 11 species of Brachiopods of the Rochester shale are listed from the British Wenlock limestone and also from the Wenlock shale. Two of them (*Spirifer sulcatus* and *Rhynchonella borealis*) do not appear above the Wenlock limestone. Below the Wenlock shales 8 of them appear in the Woolhope limestone, 8 (with one doubtful) in the Upper Llandovery, and 7 of them range below into the Ordovician or Lower Silurian, namely, 7 in the Lower Llandovery, 4 in the Caradoc, and 2 in the Llandeilo. Above the Wenlock limestone, 8 appear in the Lower Ludlow, 4 and 1 doubtful in the Aymestry, and 3 in the Upper Ludlow. Here again the correlation is clearly with the Wenlock, and by the evidence of identical Brachiopods alone the Wenlock shales and the Wenlock limestone contain the same number of species.

COMPARISON OF THE EDMUNDS AND ROCHESTER FAUNAS

Thus by their identical transatlantic species the Edmunds fauna of Maine and the Rochester shale fauna of New York are both found to represent the Wenlock fauna of England. But on direct comparison of the Edmunds and Rochester it appears clear that they are not identical faunas.

Confining our attention now to Brachiopods exclusively, we find 6 of the transatlantic species of the Edmunds fauna also appear in the Rochester fauna, namely, *Pholidops implicata, Dalmanella elegantula, Rhipidomella hybrida, Leptæna rhomboidalis, Spirifer crispus,* and *Atrypa reticularis.*

In the Rochester fauna are listed 3 transatlantic species not detected in the Edmunds fauna, namely, *Plectambonites transversalis, Spirifer sulcatus,* and *Spirifer radiatus,* two of which do, however, appear in the underlying Dennys formation of the Eastport district.

PLACE OF THE SIGNIFICANT BRACHIOPODS OF THE EDMUNDS FAUNA IN THE TYPICAL SILURIAN SECTION OF ENGLAND

The Edmunds fauna contains 7 transatlantic species not recognized in the Rochester shale, some of which are known to appear in higher formations of the New York section. As these 7 species are particularly significant for this discussion, the following list is presented:

Monomerella woodwardi Salter.
Leptostrophia filosa Sowerby.
Strophonella euglypha Hisinger.
Strophonella funiculata McCoy.
Pentamerus galeatus Dalman.
Meristina tumida Dalman.
Wilsonia wilsoni Sowerby.

Restricting our attention to these 7 significant Brachiopods of the Edmunds fauna, the question arises what is their relationship to the transatlantic series of formations? In making this comparison I will select the standard Wenlock section of Shropshire, situated in the center of England, of the faunas of which a very full and detailed study was made by Mr. George Maw, and the exact range and frequency of individuals of each species of Brachiopods was listed by Davidson in his "Supplement to British Silurian Brachiopods."[6]

In that section the beds are more finely divided stratigraphically than in the more familiar general section of England and Wales. The stratigraphy of the Shropshire section from above downward is as follows:

		Feet.
Ludlow series ..	Passage beds (Linley Brook)........ Upper Ludlow...................... Aymestry limestone................	collectively, 1,200–1,400
Wenlock series.	Shales over the Wenlock limestone..............	100
	Wenlock limestone..............................	80– 90
	Upper Wenlock shales (Tickwood beds)...........	300– 500
	Middle Wenlock shales (Coalbrookdale beds)......	100–1,200
	Lower Wenlock shales (Buildwas beds)...........	80– 100
	Basement beds, or Buildwas Park beds, Lowest Wenlock shales..............................	500– 600
	Upper Llandovery..............................	160– 170

Five of the 7 Edmunds species are listed from the Wenlock limestone; the 3 (*Leptostrophia filosa, Strophomena euglypha,* and *Strophonella funiculata*) rare, and the other 2 (*Pentamerus galeatus* and *Meristina*

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[6] British Silurian Brachiopods, Supplement, 1882, pp. 72-74.

tumida) common. The remaining 2 species are not represented by name in the Wenlock limestone of this section, but their specific characteristics are recognized in the fauna, as shown by the following statement:

Dinobolus (*Monomerella*) *davidsoni* Salter (of which Davidson regarded *M. woodwardi* Salter as a variety) is listed by Davidson in the Shropshire section from the Wenlock limestone. The variety *woodwardi* is the form recognized in the Edmunds fauna. This variety (*M. woodwardi* Salter) is reported in the Woolhope district farther south from the Wenlock limestone by Salter. *Wilsonia sphæroidalis* McCoy is regarded by Davidson as a small variety of *Wilsonia wilsoni* Sowerby. (See British Silurian Brachiopods, page 170, where it is called *Rhynchonella wilsoni* var. *sphæroidalis* McCoy.) In the Shropshire section *R. sphæroidalis* is very rare in the Buildwas beds or Lower Wenlock shales and common in the (Tickwood) Upper Wenlock shales and in the Wenlock limestone, and *Rhynchonella wilsoni* is marked "common" in the shales overlying the Wenlock limestone and in the Lower Ludlow, Aymestry, and Upper Ludlow. In the Malvern, May Hill, and Usk districts, farther south, *R. wilsoni* is reported by Salter from the Wenlock limestone.

Thus it appears that the 7 Brachiopods by which the Edmunds fauna is distinguished from the Rochester fauna occur in the typical Wenlock limestone of England, though 2 of them are restricted to its southern extension. None of them, moreover, have a range downward in the Shropshire section farther than the Tickwood beds immediately underlying the Wenlock limestone except *Meristina tumida,* which is marked "very rare" in the Lower Wenlock shales (Buildwas beds), while 4 of them range upward into the Lower Ludlow, 3 into the Aymestry, and 2 into the Upper Ludlow of this same section.

Again, all of them are distributed southward in the Wenlock beds of the southern English and Welch districts.

Following the Wenlock beds northward into North Wales and southern Scotland, the rarity of any one of these 7 species is conspicuous. For instance, the list of the Silurian fossils of the south of Scotland in the collections of the Geological Survey of Great Britain[7] records from the Wenlock limestone only *Whitfieldia tumida* and *Rhynchonella wilsoni* of this list of 7 significant Brachiopods from the Edmunds. It includes, however, the following species, which are typically Wenlock species: *Pholidops implicata, Cyrtia exporrecta, Plectambonites transversalis, Nucliospira pisum, Bilobites biloba, Dalmanella elegantula, Spirifer sul-*

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[7] **Memoirs of the Geological Survey of Great Britain, vol. 1, Scotland, 1899.**

catus, several of which, as has before been mentioned, do not belong to the Edmunds fauna, but do belong to the Rochester shale fauna of New York.

EDMUNDS SPECIES IN THE GOTLAND SECTION

Following the distribution of Wenlock species from England eastward to the Gotland section, we find all of the 7 significant Edmunds species listed from the "Medel Gotland" formation by Lindström.[8]

It is to be noted regarding this Gotland section that the faunal and stratigraphic sequence has been more fully determined by later studies. Hedström, in his review of the Silurian for the International Congress of 1910, showed that there are in the Gotland section two separate horizons at which *Pentamerus galeatus* appears. In the Lower Gotlandian, "Lower Cliff level number II" of Hedström, *Pentamerus galeatus* appears with *Dinobolus davidsoni, Atrypa imbricata, Rhynchonella borealis, cuneata, sphærica, Orthis biloba, O. hybrida, Spirifer plicatella*, and *Plectambonites transversalis*, thus combining the Edmunds and Rochester peculiar species as in the English Wenlock. In the highest zone, "zone VII" (called by Hedström "genuine Upper Gotlandian"), *Pentamerus galeatus* is again recorded in connection with such other species as *Orthis elegantula, Spirifer plicatella, Rhynchonella wilsoni*, and it includes also *Halysites catenularius;* but this fauna does not contain the characteristic species *Plectambonetes transversalis, Rhynchonella cuneata*, or *Orthis bilopa* of the Rochester shale.

THE BOHEMIAN FAUNA E^2

In the fauna E^2 of Barrande, from Bohemia, we find the following British Wenlock species definitely recognized by name:

Atrypa linguata Buch.
Atrypa marginalis Dalm.
Atrypa reticularis Linné.
Cyrtia exporrecta Wahl.
Leptæna transversalis Wahl.
Meristella tumida Dalm.
Orthis elegantula Dalm.
Pentamerus linguifer Sow.
Retzia barrandei Davidson.
Rhynchonella cuneata Dalm.
Rhychonella deflexa Sow.
Spirifer sulcatus His.
Strophomena euglypha His.
Strophomena funiculata McCoy.
Strophomena pecten Linné.
Strophomena rhomboidalis Wilck.

Besides these a large number of species of the genus Spirifer, given new names but belonging to the group of the Radiati, both the plicate and the non-plicate forms, such as in England are called *Spirifer radia-*

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[8] G. Lindström: Bidrag till Kannedomen om Gotlands Brachiopoder. Ofversigt af. Kgl. vet. Akad. Forhandlinger, 1860, pp. 380-382.

tus and *Spirifer plicatella.* There are also several species under special names that represent forms called *Spirifer crispus* and *Spirifer elevatus* in the English Wenlock.

Pentamerus galeatus Dalman is recognized in the Bohemian section, but it does not appear till the fauna F², and though numerous closely related forms of Rhynchonella are figured under special names, *Rhynchonella wilsoni* Sowerby is not listed till fauna F².

It would lead us too far afield to discuss the Barrandean species, but sufficient evidence is given in the species named to show that in the Bohemian fauna E², as in the Wenlock faunas of England, are found associated in the same fauna species which are separate in the two North American Niagara faunas, namely, the Rochester and the Edmunds faunas.

THE PODOLIAN FAUNAS

Turning still farther east and south to the government of Podolia, Russia, we discover the conditions described below, as expressed in the faunas of the three zones of Silurian, called I, II, and III in Wenjukow's paper.[9]

His zone I is correlated with the Wenlock shale of England, the Mergelschiefer und sandstein of Gotland (*c*), and E *e*¹ of Bohemia. It contains *Orthis elegantula* and *hybrida, Bilobites biloba, Leptæna transversalis, Strophomena rhomboidalis, Strophonella euglypha, Atrypa reticularis, Spirifer crispus* and *elevatus, Cyrtia exporrecta, Whitfieldia tumida, Pentamerus galeatus, Rhynchonella sphærica.*

Several of these species occur also in the zone II, which is correlated with the Wenlock limestone, Lower Ludlow, and Aymestry of the English section.

The species *Orthis elegantula, Strophomena rhomboidalis, Chonetes striatella, Atrypa reticularis, Spirifer elevatus, Spirifer crispus, Pentamerus galeatus,* and *Rhynchonella wilsoni* continue upward to the zone III, which is made the equivalent of the Upper Ludlow and reaches up to fauna F² of the Bohemian section.

What is noticeable in this section is the absence of the plicate forms of the radiate spirifers; the prominence of forms of the *Spirifer elevatus-crispus* type; the absence also of the *Spirifer sulcatus.* A form very closely related to *Strophonella funiculata* McCoy is named by Wenjukow *Strophonella semiovalis.*

Here is evidence of the predominance throughout this section of the particular combination found in the Edmunds, with less evidence of the Wenlock forms peculiar in the Rochester fauna of New York.

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[9] T. Wenjukow: Die Fauna der Silurischen Ablagerungen des Gouvernments Podolien. St. Petersburg, 1899.

SUMMARY OF THE FACTS OF CORRELATION

I have now presented enough of the facts to make clear the problems to which I wish to call attention.

The faunas of the Rochester shale of New York and the Edmunds formation of Maine differ considerably in composition, but a close comparison of the particular species of each shows that each of them finds its nearest correlate in the British Silurian at the same horizon, namely, the Wenlock limestone and immediately underlying shales.

Examination of the species distinguishing these two faunas shows that the peculiar species of the Rochester fauna have closer affinity in the English section with the faunas *below* the Wenlock, and the peculiar species of the Edmunds show closer affinity with faunas which *follow* the Wenlock.

The hypothesis suggested by the facts is that there are here concerned two faunas which are found on this side the Atlantic in separate areas of distribution, but in England are blended together in the typical Wenlock district.

This hypothesis seems to be supported by the increasing dominance of the Edmunds group of species in the Gotland district and the conspicuous decrease in importance of the Rochester group of species still farther east and south in Podolia; also by the very slight expression of the Edmunds group of species anywhere on the North American continent.

It will be noticed that the correlation of the Edmunds and Rochester faunas with the transatlantic Wenlock is established on statistical evidence of identical species.

The hypothesis of the distinctness of the Edmunds and Rochester faunas is based on the statistics of range and distribution of the species, namely:

Certain species common to the Edmunds, Rochester, and transatlantic Wenlock faunas are notably of long range below and above the Wenlock and of wide distribution.

The transatlantic Wenlock species found in the Rochester and not in the Edmunds fauna are conspicuous for ranging lower in the series rather than higher, for holding on in the northern extension of the Wenlock of Great Britain, and for becoming less conspicuous in the far east European distribution. On the other hand, the peculiar species common to the Edmunds and Wenlock faunas are conspicuous for their higher rather than lower range in North America, England, and southern Europe, and for their conspicuous appearance in the Silurian faunas of England and Gotland, Bohemia and Podolia, but their absence from the corresponding Silurian faunas of interior America, though having representation in several cases in faunas of recognized higher horizons.

Thus far the conclusions reached seem to rest on what we may regard as established facts, the certitude of which can be verified by examination of the specimens.

When we go further and attempt to interpret the presence or absence of certain so-called identical fossils into time-relations of the formations containing them, and still further try to reconstruct from them the geography of the earth's surface at some particular stage of geological time, we are obliged to bring in assumptions which do not find their verification in observed characters of the fossils, but are based on biological hypotheses and even metaphysical conceptions we have been accustomed either to neglect or take for granted rather than examine with the same care we devote to identification of species.

It is to these hypotheses and assumptions that I particularly wish to call attention in what follows:

PART II. PROBLEMS INVOLVED IN CORRELATING FOSSIL FAUNAS

GENERAL CONSIDERATIONS

What has previously been said concerns the observed facts in the case. In the present discussion I will ask you to take it for granted that they are correctly stated, because for the purposes of this paper a hypothetical case would serve as well as a real one, provided the conditions assumed were all natural and in accordance with observed facts.

The chief purpose I have in writing this paper is to call attention to the rather remarkable number of inferences we are accustomed to draw in framing our ideas in paleontology, stratigraphy, and paleogeography, which, though they appear to rest on what we regard as established, observed facts, may have very little or no logical connection with them, or may be so loosely or so irrationally applied as to render the conclusions unsound or positively false.

The case is like this: I have examined the fossils taken from the Edmunds formation of the Eastport quadrangle, Maine, and listed them under scientific names. Whenever I could find a name which had been already applied to the characters observed in species of the Edmunds fauna I used it. If new characters were discovered I have described the form under a new name. In making comparison with the fossils of formations already described, I have used what may be called the *statistical* *method,* which I presume paleontologists in general use in determining correlation of formations. In my case I have adopted several rules which I regard as of prime importance, namely:

1. To establish correlation between two fossil faunas it is essential to bring into comparison *identical,* not closely related *species.*

2. It is essential in listing the species of a fauna to include only those species which are actually found *associated together* in the same stratum in the same locality, or when several local faunules are combined only those local faunules may be listed together that have combined enough of the same species to certify that they are *samples* of the *same fauna.*

This precaution is required to eliminate such differences as may arise by alternation of one or more faunas in the same general formation, or by change in the original environmental condition often expressed by differences in the lithological constitution of the sediments, or by differences arising from geographical distribution.

Other rules may have been applied, but these two are essential if we expect to reach precision in correlation.

Having in this way built up a list of the contents of the Edmunds fauna of Maine, in order to apply the same rules in the transatlantic fauna compared, I found the typical Wenlock series of England is expressed in the Shropshire section, as reported in Davidson's Supplement of British Fossil Brachiopods, which has been treated with the same kind of precision so far as Brachiopods are concerned. This is taken as the standard of comparison for the English sections. In making comparison with the general Niagara fauna of the country I have used the fauna of the Rochester shale of New York as the standard of comparison.

In applying the statistical method I have adopted the following rules:

3. To establish correlation, species of the *same class* must be compared. In the present case the class of Brachiopods are used because the statistics regarding that class have been most thoroughly elaborated.

4. The particular horizon in the standard section with which equivalence is found in the compared section is determined by the *number of identical species.*

Thus in the case before us, comparing the Edmunds fauna with the general Silurian faunas of Great Britain, I found 18 species identical with species of the transatlantic Silurian; 17 of them are listed in the Wenlock limestone and shale, 3 do not appear above the Wenlock limestone, 16 appear in the Woolhope, 14 and 1 doubtful in the Upper Llandovery, 12 appear in the Ordovician, namely, in the Lower Llandovery and Caradoc, and 4 as low as the Llandeilo. Above the Wenlock 12 appear in Lower Ludlow, 11 and 1 doubtful in Aymestry, and 4 in Upper Ludlow.

Thus by the statistical method the Edmunds fauna is correlated with the general Wenlock limestone and shale of Great Britain, because in these beds the number of identical species is found to be greatest.

Using the more refined method and comparing the Brachiopods alone with the Brachiopods of the Shropshire section of England, the same result is reached. The largest number of species of Brachiopods of the Edmunds fauna are found in the Wenlock limestone and immediately underlying shale, and running below and above that horizon the number of identical species regularly decreases until they cease to appear.

As has been shown in the first part of this paper, taking the fauna of Rochester shale of New York and comparing it with the same transatlantic faunas, the correlation is the same—the Wenlock limestone and immediately underlying shale—the diagnostic brachiopods in that case being represented in great number in the limestone and shale. Nevertheless, the Edmunds fauna and the Niagara fauna of New York as represented by the Rochester shale do not agree. The Edmunds and Rochester faunas contain 6 identical Brachiopods in common; 3 of the transatlantic species in the Rochester shale have not been seen in the Edmunds formation. In the Edmunds fauna 6 identical species of the transatlantic Wenlock fauna have not been recorded from the Rochester shale. These peculiarly Edmunds species are regarded as of particular significance in determining the true relations of the Edmunds to other formations.

PROBLEM I

Definition of the problem.—The first of the problems I will define as follows:

Given two faunas separated by considerable distance from each other and by this statistical method shown to be correlated, what inference can be drawn as to the *time-relations* of the formations carrying the faunas? Are they contemporaneous? and what are the grounds for deducing from fossils in the rocks inferences regarding the time-relations of the geological events represented by the rock formations and all the other problems connected with paleogeography?

Huxley warned us against interpreting likeness of fossils or sediments into contemporaneity. Since that statement was made much progress has been made in biology as well as geology, and now it may be profitable for us to turn our attention away from the fascinating attraction of the scientific details of our science to consider some of the fundamental *prin-*

ciples underlying our work, and look afield and take our bearings and see whither we are drifting.

It is quite evident that the general practice of making correlations and locating our formations in horizontal parallels means to us that the correlated formations were deposited at synchronous intervals of time the world over. The reconstruction of the world's geography is based largely on the assumption that correlation of fossil faunas may be directly translated into contemporaneity, and we are apt to forget the many preconceptions involved in such translation. Let us call attention to some of them:

A. *Identical species.*—We speak of *identical species.* What does that mean? I have listed among the identical species *Strophomena rhomboidalis* Wahlenberg. This species is listed in formations ranging from the Ordovician to the Carboniferous.

Also I have listed *Strophonella funiculata* McCoy, the total range of which in the Shropshire section is from the Tickwood beds underlying the Wenlock limestone to the Lower Ludlow. It occurs in the Edmund fauna, but I can find no evidence of its record from any other formation in America.

By the statistical method I have been obliged to use these two species as *units of equal value* in determining the horizon. What is the difference between them that makes the one to be regarded as ranging through four geological systems, the other to be restricted to a single fauna appearing in a limited area? *Strophomena rhomboidalis* presents in its various forms as great an amount of morphologic diversity of characters as do the genera *Strophodonta, Strophonella, Leptostrophia* taken altogether, with all the many species described in their genera.

In the comparison of the Edmunds with the transatlantic Wenlock, both of these types of species are in evidence, but the fact is that the larger number of the species found to be identical in the two faunas are of long stratigraphic range; also of wide geographical distribution, and those of the type of *Strophonella funicula* are rare.

Not only is this true, but in making up a list of identical species there is generally some degree of direct relationship between the species which have a long stratigraphic range and identity in widely separate regions of the earth.

B. *Plasticity and fixity of form.*—The contrast between the two species (mentioned as examples) does not end with the above statement.

Such a species as *Leptæna rhomboidalis* has come to be regarded as a single species not because all the specimens are morphologically alike, but because they are so commonly variable. Any set of specimens taken from the same beds varies greatly in form, and this plasticity of form is not confined to samples taken in any special stage of its long history or any particular locality of its wide distribution.

On the other hand, a species like the *Strophonella funiculata* presents slight degree of variation in its specific characters and is itself a special phase of the more widely variable *Strophonella euglypha.* In what are regarded its generic as well as its specific characters, specimens found associated in a single fauna or a single locality are not markedly different and hence fall under a more rigid definition. In the case of a long-lived species like *Strophomena rhomboidalis,* which retains its morphologic plasticity, the conclusion seems reasonable that it lived and flourished continuously somewhere throughout the whole time represented by the four geological systems in which it is found, and that its presence or absence in any particular formation of those systems was determined by favorable or unfavorable conditions of environment, and therefore can not be taken as evidence of contemporaneity of the particular formations holding the species except within the limits of its known existence in the series.

In the other extreme case of a short-lived species like *Strophonella funiculata,* which in any particular section is known to have a short vertical range and to preserve its specific characters rigidly, we are led to a similar conclusion. If we start with the assumption that its peculiar morphologic characters are the reflex response of the organism to particular conditions of environment, what is there to prevent the recurrence of such response in the race to which it belongs at any recurrence of the appropriate conditions? If, on the other hand, we assume that it was a phase of race-evolution, not being capable of adapting itself in the struggle for existence and therefore closely adjusted to a particular set of environmental conditions, the meeting of the same species in rocks of two widely separate regions, such as Maine and the center of England, calls for time to migrate, and the further apart the locality of the faunas the longer the time interval separating them. In neither of these extreme cases are we safe in inferring identity of time from the presence of identical species, and most of the species of a fauna are intermediate between these extreme examples.

C. *Personal equation of the describer of species.*—But these are not the only problems involved in interpreting identity of the species of two faunas into contemporaneity of the formations containing them.

The *personal equation* of the describer of the species listed must be eliminated before we can reach exact conclusions.

For instance, Barrande, who prepared a monumental set of volumes illustrating the Silurian system of Bohemia, made a list of 49 species of Spirifers in the one fauna E^2. These volumes were published in 1879.

In Murchison's Silurian System of Great Britain, published in 1839, Sowerby described the fossils and recognized only 12 species under that generic name—Spirifer. The Brachiopods were later thoroughly studied by Davidson, and in 1883, after a life study of them, his final list of all the British Silurian Brachiopods known to him when the final supplement was published (in 1883) contains only 5 species (and 3 varieties of 1 of the species) of the genus *Spirifer.*

Only one of the names used by Barrande was a species previously recognized by another author; 48 of the 49 species he labeled as new species.

In Davidson's list 3 of the species recognized were described by foreigners before Sowerby, 2 of them by Sowerby; 1 is a species of McCoy, and 1 of the varieties is by Salter, both of the latter working chiefly on British species.

Although the lists would seem to indicate that the Bohemian fauna was extremely rich and unique in species, examination of the figures shows that Barrande's 49 species of Spirifer, of E^2 Bohemia, belong almost entirely to modifications of the 5 species listed by Davidson from the British Silurian. There are some peculiar forms not recorded by any of the figures of Davidson; but the Bohemian series presents very little morphological digression from the group of forms described as 5 species by Davidson.

This is but an extreme case of the different conceptions of species held by authors.

Not only is there great difference in the plasticity of characters of natural groups of specimens listed under a single specific name, but there is a great difference among authors in the application of specific names to the specimens under examination.

This analysis shows that a list of identical species by which we attempt to correlate the faunas of two geographically separate formations differ widely in many respects, namely: (1) in the amount of *morphologic divergence* compatible with specific identity; (2) in the *range* or stratigraphic thickness of the sediments through which they are known to persist; (3) in the *distribution* or wideness of the geographical area in which they may be found, and, what is of still greater importance in estimating their value for correlation, (4) in the wide *divergence of* *usage* in the application of the specific names to morphologic characters of the fossils described.

The effect is to make a list of identical species to be composed of a group of morphologic units of *very diverse* scientific value.

We would not expect to get accurate results regarding geographical boundaries by promiscuously adding together yards, feet, and meters, and can we expect to reach correct conclusions regarding correlations by comparing statistics of such diverse meaning. In the past fifty years a great amount of attention has been given to establishing uniformity of classification and nomenclature of geologic formations. I raise the question whether the time is not ripe for us paleontologists to give thought and study and conference to solving the difficult problems facing any one who attempts seriously to correlate formations by means of their fossil contents.

PROBLEM II

General discussion of the problem.—The second problem to which I wish to call attention concerns the use of fossils in making inferences as to the physical conditions of the area in which they lived and the geological events signified by change in fossil faunas.

In what I have to say you must bear in mind that my scientific study of fossils has been limited to Paleozoic faunas, the great part of the species of which are now marine and extinct. Those who are more familiar with higher formations, in which living genera and species come into evidence, and students of land fossils of higher biological rank may contribute valuable suggestions in the solution of these problems which I can not speak of from personal knowledge.

In the study of Paleozoic faunas we have reached certain conclusions regarding the original nature of the environmental condition under which the fossils lived by noting the physical character of the sediments and in a general way by observing the adjustments now existing of the classes of organisms represented in these ancient faunas. Thus when we discover a fauna limited to Lingulas, a few frail mollusks, and fragments of fish remains and driftwood we interpret it as evidence of shallow water marine environment.

When we discover corals in abundance, Brachiopods and Cephalopods dominant in the composition of the fauna, and the sediments more or less calcareous, we interpret it into deeper marine conditions, open at least to the ocean conditions as far as determination of the kind of the life is concerned.

From the coarseness and fineness of the detrital materials making up the sediments we also draw definite inferences as to nearness or distance from the origin of the materials.

The presence of salt and gypsum, uniformity of fine-grained sediments, with even lamination, ripple-marks, and cross-bedding, each has its interpretation based on the known conditions in modern oceans under which these phenomena arise.

In these various inferences we are fairly safe because we have the actual relationship of living faunas to conditions now in existence to fall back on, and we can correct our hypotheses by closer observation of existing conditions.

The difficulties arise when we attempt to draw conclusions on presumptions which are incapable of direct proof from any direct observation.

For instance, in the case before us the sequence of formations and their contained faunas in the Eastport Quadrangle area bears a very close resemblance to the sequence of sediments and faunas recorded in the Silurian district of England. In both cases there is the gradual change from pure marine sediments, with abundance of a great variety of marine invertebrates, through beds in which the types of life we consider purely marine become rare, and the species that do appear are more closely related to brackish-water species, and closing with the dropping out of all the Brachiopods except Lingulas, with traces of fish remains and frequent evidence of shallow conditions, such as ripple and wave marks, ending abruptly in a definite line of unconformity, the overlying beds being Upper Devonian instead of Silurian.

In the British section the same order of events is indicated, and the several stages in the two series are tied together by faunas carrying several identical species. Both of them indicate a gradual uplifting of the continental mass, the shallowing of the water, and the final protrusion of the surface above the sealevel, making land where for a long period of time marine conditions had prevailed.

The temptation in this, as in the first case, is to infer that the several geologic events on the two sides of the present Atlantic Ocean were contemporaneous in this Silurian period of time.

Let us examine the hypotheses on which such a conclusion rests.

First, we have to assume that the identity of species in the separate faunas indicates contemporaneity for the several formations in which they lie.

In the discussion of the Edmunds fauna it was discovered that a majority of the species which can be regarded as identical with transatlantic species in the Wenlock have a range in the Silurian rocks of England as great at least as the whole series of beds represented in the Silurian of the Eastport region, and some of them appear both in Ordovician and Devonian strata.

Supposing we accept the proposition that the order of succession of the fauna points correctly to a gradual lifting of the sea bottom to the surface in the two areas, is not the testimony as strong evidence that the several faunas indicate only like conditions of environment as that they indicate contemporaneous periods of time?

Which of these two conclusions we adopt will depend in great measure on which of two diverse hypotheses we accept regarding the causes of change in form of organisms. For convenience, call these two the hypothesis of migration and the hypothesis of evolution.

Hypothesis of migration.—By the hypothesis of migration I mean that in seeking an explanation for the change in composition of the fossil faunas we adopt the hypothesis that the changes in the environmental conditions under which the fauna of the lower formation lived resulted in the departure of that fauna from the area under examination, and a new set of species adjusted to the new conditions migrated into the area.

In this hypothesis several propositions regarding the relations of the morphology of species to conditions of environment are involved.

1. It is assumed that a species maintains its morphologic characters and adjustment to conditions of life, and when in one locality the habitat becomes unfavorable the species migrates or moves out to find more congenial conditions or dies.

2. There is also involved the assumption that the overlying fauna was already flourishing elsewhere during the time of occupation of the area by the lower fauna, which means that although in the geological section the one fauna makes its record later than the other the two are actually contemporaneous faunas adjusted and living under diverse physical conditions at the same time.

And these two propositions appear to be well founded on observed facts in present-time conditions—that is, we know that at the present time there are living in the oceans quite diverse faunal combinations of species—more or less closely adjusted to differences of depth in the water, different degrees of purity and density of the salt water, differences of temperature, and also limited to particular geographical provinces of distribution.

We seem, therefore, to be fully justified in assuming that a similar set of conditions prevailed in Paleozoic time.

Evolution hypothesis.—The other hypothesis, the evolution hypothesis, rests on two almost diametrically opposite propositions.

I. The first of which is that a species subjected to unfavorable conditions of environment adjusts its morphologic characters, and that the differences observed in the faunal composition between a given fauna and the fauna stratigraphically underlying it is the result of modification of those species capable of making the adjustment and the killing off of those not capable of adjustment.

II. The second proposition is that the second fauna is really a newly evolved fauna, not contemporaneous with the first, but actually represents a later period of time wherever it is found.

This evolution hypothesis also appears to be founded on well known facts of geographical distribution and what we know of the effects produced on living species by abnormal conditions of environment to which they are exposed.

This second set of problems, like the first, is familiar to us all; but are we aware of their great significance in reaching right interpretation of our fossils? Are we not unscientific in supposing that our hypotheses, our assumptions, our fundamental ideas, our modes of reasoning, will take care of themselves if only we accurately record our observed facts?

The problems to which I have referred confront us all when we attempt to interpret fossils. It is easy to state what they are, but their solution will require serious consideration if we are to make real progress in our science.

Conclusions

In conclusion, I will state that after a study of the facts available I feel a reasonable confidence in correlating the fauna of the Edmunds formation with the fauna of the Wenlock limestone and shale of England. But the facts do not seem to me to warrant the statement that the Edmunds formation and the Wenlock are contemporaneous in any such sense as to enable us to draw definite geographic boundaries of some particular epoch of geologic time.

The problems to which I have called attention do not involve uncertainties regarding the morphologic characters of fossils, but uncertainties regarding the modes of thought and reasoning, the controlling ideas, by which we interpret fossils into terms of time-relations and paleogeography.

Considering the importance of having right premises even in scientific reasoning, may it not be worth our while to examine more closely the presumptions we are accustomed to use in interpreting fossils.

Discussion

In reply to Mr. Ulrich's criticism, I will state that I did not intend either to affirm or deny that all differences expressed by contrasted faunas are the effect of changed conditions of environment, but to call attention to the fact that we paleontologists are accustomed to use in our interpretation of faunas the hypotheses of migration and of modification without due consideration of the diametrically opposite theories regarding the behavior of organisms when subjected to adverse conditions of environment.

When we infer from the morphologic differences presented by the species of two contrasted faunas that migration has taken place, we assume that a species either maintains its characters or dies when subjected to adverse conditions of environment. When, on the other hand, we cite the same morphologic differences as evidence of successive stages in the evolution of the species, we are working on the hypothesis that the species modifies its character either in direct response to changed conditions of environment or by orthogenesis, irrespective of environment.

It is important to know which of these conceptions of the behavior of organisms is correct and applicable to the case in hand.

To the second point, that locally slight differences in the morphology of fossils are of great value in tracing the stratigraphic continuity of beds, I reply certainly this is true. In attempting, however, to correlate beds separated by considerable distances, and possibly in separate geologic basins, such slight variations in form are of little value so long as they do not exceed the limits of normal fluctuating variation expressed by the species at a single horizon when represented by abundant individuals.

In answer to Doctor White's question, I would state that the Mascarene beds across the boundary in New Brunswick are correlated with the Eastport formation of the section in Washington County in the southeast corner of Maine.

To Professor Grabau's suggestion that the varietal characters expressed by *Strophomena rhomboidalis* are gerontic in nature, it may be replied that while it may be possible to detect in the Carboniferous some evidences of old age characteristics, it is the fact that from beginning to end the species expresses a great amount of variation, and the plasticity of form is continued with recurrences of the species as we follow it upward in the column. The species passes through considerable modification of form in passing from embryonic to adult stage, but so far as I have observed, these developmental stages are not expressed in phylogeny with sufficient distinctness to be of value in marking the stages of the history of the race.

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EARLY PALEOZOIC DELTA DEPOSITS OF NORTH AMERICA[1]

BY AMADEUS W. GRABAU

(*Read before the Society December 29, 1911*)

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[1] Revised manuscript received by the Secretary of the Society January 22, 1913.

This paper was presented before the Society on December 29, 1911, in its entirety under the title "Ancient Delta Deposits of America and Europe." It was awarded a Walker prize by the Boston Society of Natural History in May, 1912. The present part has since been much enlarged by the addition of details. The general conclusions are, however, the same. The fieldwork in the Appalachians was carried on under a grant from the Esther Herrman Research Fund of the Scientific Alliance of New York (now New York Academy of Sciences and affiliated societies).

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INTRODUCTION

RIVER DEPOSITS

In recent years it has come to be generally recognized that within the stratigraphic series of both the old and the new world there are a number of deposits which owe their origin and characteristics not so much to the ordinary forces active in marine sedimentation, but rather to the dominance of the influence of water on land. Most noteworthy among these are the deposits formed by rivers, those formed by lakes or other standing water bodies being of secondary and limited significance.

River deposits may be divided into (1) interstream deposits, or those formed along the course of the stream—that is, on its floodplain—and (2) terminal deposits, or those formed at its debouchure either at the foot of the mountains or at its junction with the sea or a lake. Considering only the last type, we find that in the first case a dry delta or alluvial fan or cone results, while in the second a delta of the ordinary type, partly subaërial and partly subaqueous, is formed. The general characteristics of these two types of deposits when formed by modern streams are well known and have been fully described.[2] They may therefore be passed over briefly:

CHARACTERS OF THE ALLUVIAL FAN

The essential difference between the alluvial fan and the delta lies in the simple character of the first as compared with the complex one of the second. The beds of the alluvial fan will be essentially of one kind—that is, topset beds—though they may vary in texture, thickness, continuity, and other characters. These beds are chiefly of subaërial origin, though the fan's foot may dip into the sea or a body of standing water. The increase in size will be a semi-radial one, though showing more or less irregularity according as one or the other of the distributaries will build faster than its neighbors. In grain the individual beds will vary from coarsest along the distributaries, especially near the head of the fan, to finer in the spaces between the distributaries and finest as a whole near the periphery of the fan. Owing to the frequent shifting of the distributaries, these features will vary in harmony with such shifting and the variation will increase in magnitude as the alluvial fan grows.

CURRENT BEDDING OF THE ALLUVIAL FAN DEPOSITS

Two kinds of current bedding may be observed in alluvial fan deposits: (*a*) compound oblique bedding and (*b*) complex cross-bedding. The former is characterized by a succession of oblique layers, all of them inclining in the same direction, at approximately uniform angles, and separated by horizontal beds of less thickness (figure 1). This type of cross-bedding is eminently characteristic of torrential stream deposits.[3] The direction of inclination indicates the direction of the current, and since in a fan this direction changes around the periphery such change must also be looked for in the direction of the dip of the layers in various contemporaneous parts of the formation. Such a type of cross-bedding resembles essentially a series of superposed deltas of small height, each consisting of foreset and topset beds. The foreset beds become tangent toward the bottom, as in ordinary deltas, merging into the underlying horizontal beds, which in turn constitute the topset division of the next lower series. The topset beds are generally somewhat coarser than the foreset beds, and it not infrequently happens that the topsets of an earlier part of a series are somewhat lower than those of the later part of the same series. Generally a sharp contact is shown between topset and foreset beds, the latter showing evidence of a certain amount of truncation before the topset beds were laid down. In general the layers showing the oblique bedding are not more than 3 or 4 feet in vertical thickness, but the individual oblique beds may be 6 feet or more in length. The topsets are usually not more than half as thick as the oblique series. The angle of inclination of the oblique series varies with the grain of the material and other factors, but generally falls around 30 degrees from the horizontal. In some cases as many as six or eight or even more successive series

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[2] Herman Credner: Die Delten. Petermann Geographische Mittheilungen. Ergänzung, heft No. 56, pp. 1-74, 3 tafeln. 1878.

Joseph Barrell: Bull. Geol. Soc. Am., vol. 23, pp. 377-446. 1912.

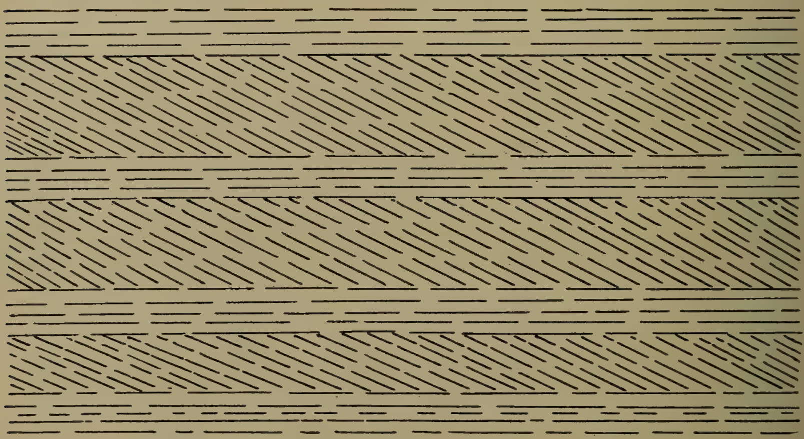

FIGURE 1.—*Diagram of compound oblique Cross-bedding*

The type most common in torrential deposits of this kind, each consisting of inclined foresets and horizontal topsets, have been found superposed.

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[3] W. H. Hobbs: The Guadix formation of Granada. Bull. Geol. Soc. Am., vol. 17, pp. 285-294.

It would be difficult to conceive of a series of such deposits as having been formed in a body of standing water. A single series might be interpreted as a small delta, but a succession of such series could not be formed without periodic catastrophic subsidence after the completion of each delta. Moreover, as such subsidence brings with it a transgression of the waters, it is evident that as a result the zone of deposition would be shifted landward, and that offshore deposits would follow on the old, now submerged, delta. This type of cross-bedding is, however, eminently characteristic of subaërial torrential stream deposits, but it is wholly unknown so far from undoubted marine or lacustrine sediments. Moreover, since the deposits showing such cross-bedding are free from marine or lacustrine organic remains, though often carrying those which can be shown to be of land or river habitat, it seems that such a type of cross-bedding may be taken as strongly indicative of a non-marine-torrential river rather than a seashore deposit.

The second type of current bedding is more properly described as a cross-bedding, or better as a crisscross type of bedding, since the beds incline in all directions. The angles of inclination vary greatly, and the successively inclined series are not separated by horizontal beds, but by erosion surfaces, which may also vary in amount and direction of inclination. This sort of bedding represents a process of cut and fill on a large scale and it is most characteristic of eolian deposits at the present time. Walther[4] has described it from the Libyan desert and Huntington[5] from the deserts of Asia. One of its most characteristic features is the fact that the oblique layers, where they come in contact with the underlying erosion plane, show a marked tangency with this plane.

In the modern eolian deposits of this type the inclined strata are remnants of the anticlinal stratification of sand dunes. These dunes are partly truncated, whereupon a second set of dunes is laid down on the remains of the eroded first set. Repeating this several times will, if the layers become properly arranged, produce the structure in question. It is essentially a progressive migration of sand dunes across the truncated bases of the preceding series (figure 2).

While a structure of this type can be formed on a small scale by migrating ripple-marks, as shown by Gilbert,[6] it is difficult to conceive how it can be formed on a large scale except by the method of migrating dunes. It is true that a series of migrating sand-bars might produce the same, or very similar cross-bedding, except for the fact that the older sand-bars are apt to be entirely removed during the progressive encroachment of the sea, and that the areal extent of a formation built as a submarine sand-bar can be only of very limited extent, at least in so far as one of its horizontal dimensions is concerned. A structure of this kind may also be formed in subaërial delta fans wherever the material of the fan suffers rearrangement by wind.

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[4] Denudation in der Wüste. Abhand. d. Math. Phys. Classe d. K. Sachs. Gesell. d. naturw., vol. xvi, pp. 347-569. 1891.

[5] Bull. Geol. Soc. Am., vol. 18, pp. 379 et seq.

[6] Bull. Geol. Soc. Am., vol. 10, p. 139.

STRUCTURE OF THE MARGINAL DELTA

A delta built into the sea or into a body of standing water is generally much more complex than one of the subaërial type. In addition to the subaërial portion, there is the subaqueous part, which consists mainly of the foresets and bottomsets. The foresets will normally become tangent to the bottomset beds, and as the angle of the foresets decreases toward the periphery the distinction between foreset and bottomset may fade away. At the point of merging of the foreset into the bottomset beds there is often an excessive thickening over other parts of the same layer. In some deltas foreset beds may become inseparable from top- or bottomset beds.

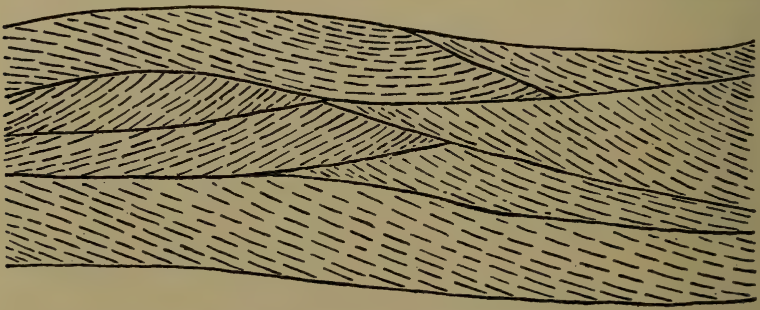

FIGURE 2.—*Diagram of complex Bedding*

Characteristic of eolian deposits

Deltas built in regions of subsidence are apt to show portions of terrestrial origin, alternating with layers of sediments carrying a marine fauna, thus indicating that a portion of even the topset beds may be formed as submarine, shallow-water deposits. Thus occasional interpolation of marine layers is to be expected in delta deposits on the seacoast, and there should be expected more or less of a mergence of the landward portion of terrestrial origin and the seaward portion of marine origin, Beyond the delta, moreover, there must be a corresponding purely marine series of deposits, formed in the open sea while the delta was building along the coast.

FOSSILS OF DELTAS

The fossils of subaërial or dry deltas, as already noted, are chiefly of terrestrial types, though on very large deltas, swamps, or even lakes may come into temporary existence, and so paludal and lacustrine organisms may occasionally become entombed. River organisms are apt to form an important part of the organic content of such dry deltas, but marine organisms are wholly wanting, except in the cases where the margins of the delta dip into the sea, or where the sea momentarily trangresses across the delta.

Seashore deltas, on the other hand, are likely to contain many remains of marine organisms, but these are generally distributed in layers alternating with others, in which remains of marine organisms are wanting and where often terrestrial organisms take their place. Remains of land and river organisms constitute a characteristic part of the typical seashore deltas, and indeed it might be considered that a delta of this type free from such remains is an anomaly and requires special explanation. Among the common type of terrestrial fossils of deltas are plants, especially the trunks of trees, which are brought down by the rivers and stranded in the delta. But river animals and plants must also be represented. Aquatic plants are often prolific in spores, especially the Rhizocarps, and such bodies might be expected in abundance. The spore cases of Chara would also be subject to burial in the delta deposits. River animals would be chiefly represented by dead parts, such as the exoskeletons of crustaceans, etcetera. In general, when a group of organisms is practically restricted to deposits of the delta type, it is reasonably safe to assume that such organisms are of fluviatile or terrestrial rather than of marine habitat.

OVERLAP RELATIONS OF DELTAS

The normal type of overlap of the alluvial fan, formed entirely on dry land, is by radial extension of the later layers, so that they transgress the margins of the preceding deposit, and each layer in turn comes to rest directly on the old surface on which the fan is building. Such overlap will be most marked around the periphery of the fan, the overlap thus being away from the source of supply. A headward overlap, or the extension of the higher layers up the stream channels supplying the material, may be brought about by the change in grade which results with the growth of the delta, and the consequent pushing upstream of the zone of first deposition. Such an overlap is, however, likely to be far less extensive and much more rapid than the overlap in the other direction, and is not likely to be confused with the marine type of overlap which is also toward the source of supply, but characterizes an extended sea-border belt rather than the contracted strip of a river floodplain.

When a delta largely of the subaërial type is building into the sea which it gradually replaces, the non-marine layers will regularly merge into a marine extension and a *replacing overlap* will result. As the continental layers extend outward, the marine layers will be shortened, and as a result the two series will be separated by an upward-slanting dividing line. Such a replacement may also occur where a submarine deposit of terrigenous material, the seaward extension of a delta, gradually spreads over one of thalassigenous or ocean-derived material, as in the case of the Hudson beds of Normanskill, Schenectady, and Utica age, which gradually replace the successive members of the Black River-Trenton limestone series from the east, the source of supply of the terrigenous material, westward.

COARSENESS OF DELTA DEPOSITS

This may vary from conglomerates and breccias, or even accumulations of large boulders, to the finest lutytes or mud deposits. The coarse conglomerate is more characteristic of the subaërial part of the delta and the fine mud of the subaqueous, but there is no especial restriction in the distribution of these deposits. Thus the alluvial fans of the Huang Ho and of the Ganges and Indus are characterized by material nearly or quite as fine as that generally accumulating in standing water, while on the other hand coarse marine deposits are not uncommon. On the whole, the texture of the material increases in coarseness toward the head of the delta or the fan, this being more or less coincident with the increase in the thickness of the deposit.

EXAMPLES OF ANCIENT DELTA DEPOSITS FROM THE ORDOVICIC AND SILURIC CONGLOMERATES AND SANDSTONES OF THE APPALACHIAN MOUNTAIN REGION

IN GENERAL

Among the many deposits of America and Europe which by their character and distribution suggest that they represent delta deposits of one or the other type above noted, only a few American examples can be selected and described in detail. Those will be chosen which, by their striking characteristics, challenge attention, and especially those with which I am personally best acquainted by prolonged field and laboratory study. I have elsewhere[7] outlined my views regarding a number of American Paleozoic formations, the characters of which stamp them as continental rather than marine deposits. Many of these are to be considered in the light of fossil deltas, and of these a few from the Ordovicic and Siluric will be chosen as illustrations of ancient delta deposits.

In the Appalachian Mountain region occur a number of conglomerates and sandstones belonging in part to the Ordovicic and in part to the Siluric systems, which by their characters show that they were deposited as deltas partly marginal, with both subaërial and submarine portions, and partly as purely subaërial or dry delta fans.

These sandstones and conglomerates were originally assigned to a uniform horizon, and correlated with similar deposits of New York which lie near the base of the Siluric. Two areas of such deposits can be distinguished: a northern, comprising Pennsylvania, New Jersey, and New York, with the centers for the most part in Pennsylvania, and a southern one centering in eastern Tennessee.

THE NORTHERN SECTION

The beds of this section form the bold monoclinal ridges of Pennsylvania, extending southward into Maryland and northward through New Jersey into the Helderbergs of eastern New York. In general, white conglomerates and sandstones have been found to rest either conformably or unconformably on the complex series of shales and sandstones known collectively as the Hudson River group, the age of which has generally been regarded as terminating with Lorraine deposits. The white conglomerates were formerly always identified with the Oneida conglomerate of New York, which nearly all geologists, following Hall, placed below the Medina, though Vanuxem distinctly assigned it its proper place at the top of the red series. In central and western New York a lower quartzite, the Oswego, which lies below the Medina as currently defined, was correlated with the Oneida, as was also the Shawangunk of the Helderberg region.

In most localities a red shale and sandstone often of great thickness was found above the lower conglomerate, or, where the latter was missing, rested directly on the Hudson River beds. This was identified with the Medina red beds of New York. In Pennsylvania a second white conglomerate or sandstone was found overlying these red beds, and this was classed as the Upper or White Medina. Darton[8] in 1896 renamed these upper white beds the Tuscarora sandstone, and the red beds beneath them he called the Juniata sandstone and shale, from the Tuscarora monocline and the Juniata River in Pennsylvania, respectively, where these formations are best shown. All the conglomerates, sandstones, and shales were subsequently united by Clarke and Schuchert under the name *Oswego group,* and as such made to represent the basal part of the Siluric,[9] a classification widely adopted in most of the recent text-books.

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[7] A. W. Grabau: Continental formations in the North American Paleozoic. Compte Rendu du XIe Congrès Géologique International, Stockholm, 1910, pp. 997-1003. 1913.

I believe I was the first to seriously question this accepted correlation, and to give reasons for the belief that these conglomerates and sandstones were not of the same age. This subject was for some years discussed before my advanced classes at Columbia University, and was especially taken into consideration during the fieldwork in the Becraft and subsequently the Schoharie regions. The subject was brought up for discussion at the Philadelphia meeting of the Geological Society of America December 31, 1904, under the title "Relative ages of the Oneida and Shawangunk conglomerates." In this communication I gave the evidence for assigning the Oneida conglomerate to a horizon at least as high as mid-Medina and the Shawangunk to the age of the Salina deposits of central New York. Mr. C. A. Hartnagel, who had been studying the Cobleskill formation of New York, also came to the conclusion that, since the Shawangunk and associated red shales and sandstones were beneath the Cobleskill, their age was to be regarded as Salina. The abstracts of these communications were not published until February 10, 1906,[*] though my own conclusions appeared in the preliminary announcement for that meeting. The full paper has, however, never been published. The subject was again considered in an address on the "Physical characters and history of some New York formations," delivered before Section E of the American Association for the Advancement of Science, at Syracuse, July 25, 1905, and published in Science of October 27 for that year.[10] In that communication the age of the Oneida was shown to be Upper Medina, and reasons were given to show that the Shawangunk was of Salina age. In the paper these beds were also considered as possibly of subaërial origin, representing delta fans formed by rivers from the old Appalachian highlands. Meanwhile Mr. Hartnagel published his observations in a paper entitled "Notes on the Siluric and Ontario section of eastern New York," which appeared in the Report of the State Paleontologist for 1903, published February, 1905.[11] Here he gave further stratigraphic reasons for assigning the age of the Shawangunk to the Salina, but regarded the Oneida as the equivalent of the Oswego sandstone. Finally, in May, 1907, he reviewed the stratigraphic position of the Oneida conglomerate, with the conclusion that it should be regarded as the equivalent of the Upper Medina. He also quotes a letter of Col. E. Jewett, published in the American Journal of Science for 1864 (volume xxxviii, page 121), in which he announced the finding of *Arthrophycus harlani* in typical Oneida conglomerate, and gives it as his opinion that the age of that rock is Medina.[12] The discovery of the Eurypterus fauna at Otisville gave paleontological corroboration to the stratigraphic interpretation, since this fauna is essentially the same as that found in the basal Pittsford shale of the Salina in western New York,[13] discovered shortly before by Sarle.

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[8] U. S. Geological Survey Folio No. 32.

[9] Science, n. s., vol. x, No. 259, pp. 874-878, Dec. 15, 1899.

[*] Bull. Geol. Soc. Am., vol. 16, p. 582.

[10] Science, n. s., vol. xxii, pp. 528-535.

It thus became evident that the Shawangunk conglomerate must be separated from the other conglomerates and placed at a higher level in the stratigraphic column. This conglomerate crops out along the Helderberg-Kittatinny-Blue Mountain Ridge, from near Binnewater, New York, to some distance beyond the Lehigh Water Gap in Pennsylvania, but with extensions southward into Maryland. The continuous mapping along the Blue Ridge of a single formation on the geological map of Pennsylvania is, therefore, erroneous, for the "Oneida" sandstone, which forms the Front Ridge northeast of the Susquehanna Gap, is the much younger Shawangunk, while the "Oneida" of that gap is the Tuscarora. In the ridges to the westward the Tuscarora and the underlying Juniata, mapped as Medina, represent, respectively, the Oneida, with perhaps some Medina, and the underlying Queenston shales of Upper Ordovicic age, as first pointed out by me in 1905. Finally, the "Oneida" of the westernmost monoclines or Bald Eagle Mountain and of some of the ridges to the east, is a still older conglomerate, the Bald Eagle, now regarded as of Lorraine age. To this conglomerate I at first gave the name Tyrone conglomerate[14] from Tyrone Gap, a name which was, however, preoccupied, and so I was forced to change it to Bald Eagle conglomerate. The equivalency of the Oswego sandstone with the upper part of this sandstone I pointed out at the Baltimore meeting of Section E of the

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[11] Bull. 80, New York State Museum, pp. 342-358.

[12] Bull. 107, New York State Museum, pp. 29-38.

[13] John M. Clarke: The Eurypterus shale of the Shawangunk Mountains in eastern New York. Ibid., pp. 295-310, plates i-viii.

[14] Science, n. s., vol. xxix, p. 355, 1909.

American Association for the Advancement of Science, in connection with the Symposium on Correlation (subsequently published). The validity of this correlation will be more fully discussed in the subsequent pages of this paper.

THE SOUTHERN SECTIONS

In eastern Tennessee and adjoining districts of the Virginias on the north and Georgia-Alabama on the south there are two series of deposits, which have as a rule been identified with the "red and white Medina" of Pennsylvania and with the Medina as a whole in New York. The lower of these is a red sandstone and shale resting on "Hudson River" (Sevier) shales. From this at various times fossils of Ordovicic types were reported, especially by Stevenson, but its correspondence to the Medina as a whole was not questioned, the fossils being regarded as mere relics of an earlier fauna in the higher beds. To this formation the name Bays sandstone was given by Campbell in 1894,[15] who regarded it as "Red Medina." I believe I was the first to point out that these beds, as well as the Juniata of Pennsylvania and the Lower Medina (Queenston) of New York and Canada, were of the age of the Richmond of Ohio and Indiana[16], and to furnish evidence for such a correlation.[17] The late Ordovicic age of this formation has since been generally accepted, though there is still some difference of opinion as to the precise correlation of these beds. This will be more fully discussed beyond.

The upper bed or "White Medina" of the southern region was originally named the "Clinch Mountain sandstone" by Safford.[18] Campbell in 1894 renamed it the Clinch sandstone (loc. cit.) and correlated it with the Medina-Oneida. The equivalency of this to the true Medina of New York and to the Oneida conglomerate is now generally held. Its precise correlation will be discussed beyond.

THE SUCCESSIVE DEPOSITS IN DETAIL

In general.—We may now consider each of these deposits in detail, beginning with the lowest, the Bald Eagle conglomerate, and endeavor to trace out the relationship of each series to the earlier and contemporaneous as well as succeeding formations. From their character and mode of occurrence, we may then attempt to determine their origin and mode of formation. As I have studied these formations for many years, examining practically all the important sections from the Helderbergs southward to Georgia and westward to Michigan and Wisconsin, and as I have further reviewed the literature on the subject and have studied a large amount of material in the laboratory, and as, moreover, I have discussed the problems of these formations with my advanced students and colleagues for years, I may, perhaps, be granted the right and ability to offer interpretations worthy of consideration.*

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[15] Bull. Geol. Soc. Am., vol. v, pp. 171-176.

[16] Science, loc. cit., 1905.

[17] Section E, Am. Asso. Adv. Sci., Baltimore Meeting, Dec., 1908. Symposium on Correlation. Journal of Geology, vol. xvii. See also Science, n. s., vol. xxix, pp. 351-356, Feb., 1909; a paper read before the Conference of Eastern Geologists in April, 1908.

[18] Geological reconnaissance in the State of Tennessee, 1st Report, 1856, p. 157.

The Bald Eagle conglomerate.—In the region of its best development today this formation is 1,319 feet thick, and consists of gray and brown sandstones, with occasional pebble beds, resting directly on and grading into the Upper Martinsburg (Hudson River) shales, which are here about 700 feet thick. The upper part of the Martinsburg shale contains a few massive calcareous beds, with poorly preserved fossils. Above this occur some sandy layers, which become more pronounced upward and assume a somewhat concretionary character. Finally, sandy beds predominate, with only some shaly layers between them, and the rock gradually becomes a solid quartzite, with ripple-marked layers. A red bed appears some distance up in the series, but red on the whole is scarce in the lower beds. The presence of one such bed, however, indicates the beginning of conditions permitting complete oxidation of the iron content of these sands during deposition, a condition which later became very pronounced. Crumplings and slickensided surfaces are common in the Bald Eagle, but I do not think that much faulting has occurred. The present thickness of the series is essentially its original thickness.

The age of the Martinsburg shale is certainly Utica, and it most probably also includes at least a part of the Eden. Ulrich, indeed, claims to have fossils from the upper beds, which indicate that they belong to the Maysville *Orthorhynchula* zone. If the faunal evidence is no more conclusive than that on which he correlated the Upper Martinsburg shales of the Mercersburg-Chambersburg area with the Eden (see beyond), it may readily be discarded. I have collected from these upper beds and carefully examined them, and I know that fossils on the whole are scarce, as well as poorly preserved, and I am convinced that correlation by the few found is a hazardous proceeding unless backed up by independent stratigraphic evidence. Now, it is just this independent stratigraphic evidence which is against such a correlation, as I shall proceed to show. Moreover, *Orthorhynchula linneyi*, and presumably its asso-

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* I make these statements in protest of the habit, repeatedly indulged in in certain quarters, of objecting to my correlations because I was unfamiliar with the sections—objections which generally ended by the adoption of my correlations.

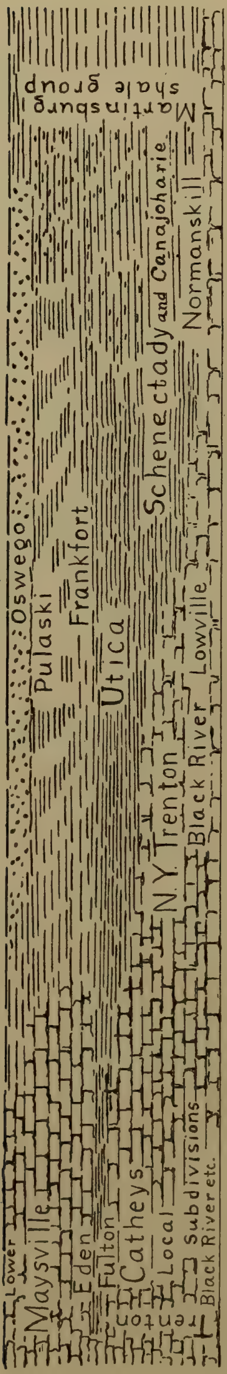
Shale Group
Martinsburg
Oswego
Pulaski
Frankfort
Utica
Schenectady and Canajoharie
Normanskill
N.Y. Trenton
Black River
Lowville
Lower Maysville
Eden
Fulton
Catheys
Local Subdivisions
Black River etc.
Trenton

FIGURE 3.—*Diagram showing the gradual eastward Replacement of the Trenton and higher Limestones by Shales of the Utica Type*

ciated fauna, is found at two distinct horizons in the Upper Ordovicic of Kentucky and middle Tennessee, according to Mr. Ulrich.[19] The first is in the Catheys formation, which Ulrich places between the Trenton and the Utica of New York. As I shall more fully show hereafter, and have shown in other publications, the stratigraphic break between the Trenton and Utica of New York thus postulated by Ulrich is absolutely non-existent. The Catheys formation of the Cincinnati dome is merely a local phase of the higher Trenton, higher, of course, than the New York Trenton, and represented in New York by black Utica shale. The Utica (Fulton) shale overlying the Catheys is merely the last of the westward transgressing mud deposits, which slowly displaced the calcareous sediments of the interior. This black mud deposit, the Utica shale type of sediment, is throughout to be regarded as the stratigraphic equivalent of the Trenton limestone series as a whole, the dividing line between the two being a diagonal one (figure 3).

The second occurrence of *Orthorhynchula linneyi* is in the Fairmount formation of the Cincinnati region. This formation, 80 feet thick, is the lowest member of the Maysville series and overlies the Frankfort or Eden shale of the Cincinnati dome region. It is generally correlated with the Lower Pulaski formation of New York. Exact correlation is here out of the question, but even should this be possible, it does not follow that the indications of the *Orthorhynchula linneyi* fauna found in the Upper Martinsburg beds of the Tyrone Gap prove this to be of Pulaski age. We have no right to assume that, because this fauna occurs in only two horizons in the Kentucky-Tennessee region, it can not also occur at an intermediate horizon at another locality. Indeed, the trilobite *Triarthrus becki* is a case in point. In the Cincinnati region it occurs in the Fulton shale of Upper Utica age, 5 feet thick. It is absent in the Lower Eden or Economy zone, 80 feet thick, but reappears in the Southgate zone, 120 feet thick, this reappearance being, according to Ulrich, about 150 feet above the Fulton. In New York, on the other hand, my students and I have collected this trilobite from the Upper Utica as well as the Frankfort shale. Indeed, it occurs in the basal 10 feet of the Martinsburg shale (Utica shale in the widest sense), which is of the horizon of the Lower Trenton. Limited thus to two restricted horizons in Cincinnati, this trilobite has a wide range where the dark muds of the Utica type have a wide range and where presumably the conditions of its existence were maintained.

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[19] Revision of the Paleozoic Systems. Bull. Geol. Soc. Am., vol. 22, p. 514.

If we now turn to the other outcrops of the Bald Eagle formation, we find a steady decrease in the thickness of this formation, both to the north and the south in Bald Eagle Ridge. Thirty miles to the northeast, at Bellefonte Gap, the thickness has diminished to 550 feet. This diminution is brought about by the failure of the lower beds and a consequent overlap of the higher, as indicated by the relation of the upper beds to the succeeding red sedimentation. These upper beds are greenish gray, somewhat ochery and micaceous sandstones, with intercalated greenish shales, while the lower series, 170 feet in thickness, is a hard gray sandstone without pebbles. It is thus seen that the formation has not only thinned, but has also changed in character away from the region which must be regarded as nearest to the source of supply. The Hudson series, at the base of the section in Bellefonte Gap, has a total thickness of about 1,000 feet. Personal observation has convinced me that it is absolutely continuous stratigraphically with the Upper Trenton limestone of this section, which is 603 feet thick, according to Collie.[20] The Trenton limestone here is characterized by *Trematis terminalis, Trinucleus concentricus, Dalmanella testudinaria,* and many other typical Trenton fossils. In the upper beds the black shales appear as intercalated members, becoming more important upward with the failure of the limestones. Finally, black shales predominate, with only a few thin limestone beds in the basal part. *Dalmanella testudinaria* and *Isoteles platycephalus* still occur, but the shales are especially characterized by *Triarthrus becki,* which, according to Collie, ranges through the lower 300 feet of these shales. The next 350 feet of the series consists of ferruginous shales, alternating with fissile black and brown shales, containing nodules of iron pyrites; these in turn are succeeded by brown, red, and gray soft shales. This formation apparently represents the Frankfort division, though fossils have not been found. The terminal 350 feet of the strata consists of soft gray and brown shales, alternating with black, slaty shales, and carrying thin sandstone beds and occasionally ferruginous limestones containing fossils. The following species are listed from these beds by Collie (loc. cit., page 417):

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[20] Bull. Geol. Soc. Am., vol. 14, p. 412.

1. *Calymmene callicephala*
* 2. *Cyrtolites ornatus* Conrad
3. *Lophospira acuminata* Ulrich
4. *Protowarthia planidorsata* Ulrich
5. *Trochonema nitidum* Ulrich
* 6. *Hormotoma gracilis* (Hall)
* 7. *Archinacella patelliformis* (Hall)
* 8. *Modiolopsis modiolaris* Conrad
9. *Ctenodonta pectunculoides* Hall
†10. *Orthodesma nasutum* (Hall)
*11. *Cleidophorus planulatus* (Conrad)
†12. *Ctenodonta lirata* (Hall)
*13. *Lyrodesma poststriatum* (Emmons)
14. *Byssonychia cincinnatiensis* Miller
15. *Orthorhynchula linneyi* (James)
16. *Rafinesquina squamula* James
17. *Dalmanella testudinaria multisecta* Meek
†18. *Zygospira modesta* Hall
19. *Platystrophia lynx* (Eichwald)
20. *Arthropora schafferi* Meek

We recognize here a number of characteristic species of the Pulaski shales of New York. These have been marked by an asterisk (*), others marked by a dagger (†) being more characteristic of the Trenton of New York. In the Cincinnati region numbers 1 and 7 occur in the Upper Trenton or Point Pleasant beds, number 1, *Calymmene callicephala*, further ranging through the entire Cincinnatian (Eden to Richmond, inclusive), as does also number 18. *Dalmanella multisecta* (number 17) and *Cleidophorus planulatus* (number 11) range through the entire Eden, the first extending also into the Mount Hope member of the Lorraine. Number 2 ranges through the entire Maysvillian of the Cincinnati region and into the Lower Richmond. Numbers 7 and 13 occur in the lowest or Economy member of the Eden, numbers 4, 5, 7, 16 in the middle or Southgate member of the Eden, numbers 9, 17 in the lowest Maysvillian (Mount Hope member), numbers 8, 9, 10, 15, and 16 in the second or Fairmount member, and number 20 in the fourth or Corryville member of the Maysvillian, while *Platystrophia lynx* (number 19 = *P. ponderosa*, Foerste) is the typical fossil of the Mount Auburn or uppermost Maysvillian. Here also occurs again the Bryozoan *Arthropora schafferi,* though it has varieties in lower and higher beds. Finally, *Lophospira acuminata* (number 3) occurs in the Middle Richmond of the Cincinnati region.

If the identifications are correct, and Mr. Collie cites Beecher, Schuchert, and Ulrich as authorities aiding him in the identifications, we have here an illustration of the impossibility of correlating the Appalachian beds with any of the specific horizons of the Cincinnati region.* Altogether, we may class these beds as the equivalent of the Pulaski of New York, and probably as the equivalent of the lower part only, the upper division, together with the Oswego, being here represented by the Bald Eagle conglomerate.

Farther northeast along the Bald Eagle Ridge, at Mill Hall Gap, the thickness of the basal sandstones seems to have increased somewhat, being 901 feet.[21] It consists of 188 feet of hard, massive sandstone immediately below the Red Juniata, mostly white or speckled with iron, beneath which occur 118 feet of softer sandstones and shales, some of them red. If we add these to the Juniata series, the thickness of the Bald Eagle becomes reduced to 595 feet. They are hard, massive sandstones for the most part, with some greenish gray speckled beds. In many cases the speckling is due to decomposed feldspar; in others to iron pyrites. Finally, in the Bald Eagle gaps of Lycoming County, the formation is reduced to about 75 feet of hard sandstone.[22] This is the northern and eastern exposure of the rock in Pennsylvania. In all cases the formation rests on the Hudson River group of shales and sandstones, but whether the contact is a conformable and gradational one or whether a disconformity and a hiatus exist has not yet been ascertained, largely for lack of satisfactory exposures. I am of the opinion, however, that where found the contact will for the most part be a conformable one, as at Tyrone Gap, the lower beds grading into the upper. If a disconformity exists, I believe that it is local and small, and such as may be expected when a continental series replaces a marine one.

Southward the thinning of the Bald Eagle beds is more rapid. In the main gap entering Milligans Cove of Wills Mountain, the southward continuation of Bald Eagle Ridge, it is only 100 feet thick and represented by a gray sandstone. Rogers and Jackson[23] suspect there may be some reduction by faulting here, but even if so this can not be very much. Elsewhere in Bedford County, south of Morrisons Cove, the Bald Eagle is not recognizable. In the westward section this is partly due to the fact that the plunge of the folds carries it below erosion level, and we are thus unable to trace its southwestern extent. Thus where Wills Creek cuts through Wills Mountain in Allegany County, Maryland, the lowest formation shown is the Juniata, the Bald Eagle not appearing. Nevertheless, there is every reason for believing that the formation soon dies out in this direction.

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* In this connection it may be well to call attention to a complete shifting of an entire fauna eastward in the Hamilton of New York, occurring beneath the Encrinal or Morse Creek limestone on Lake Erie and above it in the Genesee Valley (see Faunas of the Hamilton Group of Eighteen Mile Creek by A. W. Grabau, 15th Ann. Report New York State Geologist, p. 327 ff). Evidently Ulrich's curt dismissal of the subject of shifting faunas, so ably expounded by Williams, is due to his lack of familiarity with such examples.

[21] H. M. Chance: Report G 4, Clinton County, p. 120.

[22] F. Platt: Report G 2, p. 29.

Its occurrence in other gaps is well described in Lesley's summary[24] as follows: "Gray sandstones . . . appear in Ravers Creek Gap through Tussey [Mountain], on the Henrietta road in Woodberry township, and obscurely at two places on Bunnings Mountain; but *Oneida* [Bald Eagle] beds are certainly absent along the Raystown Juniata, in both Tussey and Evitts Mountain gaps. In fact *Oneida* [Bald Eagle] sandstone beds were seen by him [Stevenson] at no locality in Bedford County more than 35 inches thick. At the two places last mentioned there can be no question of concealment by faults, for the top layers of number 3 [Hudson River beds] are regularly overlaid by *Medina* [Juniata] red or brownish red shales, containing two fossils which unmistakably belong to that division (*Ambonychia* [*Byssonychia*] *radiata* and *Rhynchonella capax* [perhaps *Orthorhynchula linneyi*]), and the *Hudson River slates* pass without any break of sequence upward into Medina [Juniata] slates." Northeastward in Tussey Mountain the Bald Eagle and Juniata are not shown, the Tuscarora forming the base of the mountain, and resting here by overthrust on the Hudson beds, cutting out locally the lower sandstones and red beds. In Logans Gap, however, through Jacks Mountain, almost due east of Tyrone Gap, the Bald Eagle is well developed, resting on about 2,300 feet of Martinsburg shales. The basal member is 310 feet thick and consists of hard, greenish gray sandstone, mixed with pebbles of quartz smaller than those in the upper part, and hard, fine-grained sandstone, with small scattered pebbles and much disseminated iron oxide. The upper division consists of massive sandstones, reddish in color, full of small pebbles, which in some places become as large as hen's eggs. It also has a thickness of 310 feet, giving a total of 620 feet for the series. It is significant that these beds are much coarser than those farther west, showing a closer approach to the source of the material. In these beds I have observed a remarkably fine development of cross-bedding, mostly of the torrential type. The diminished thickness may be in part due to erosion, during the deposition elsewhere of the lower Juniata beds, and in part to original difference in deposition. About 25 miles west of Logan Gap, where the Juniata breaks through the mountain at Jacks Narrows, only the upper 250 feet of the Bald Eagle are brought up in the center of the anticline. They are greenish white, hard sandstones, generally free from pebbles. That the beds do not appear farther eastward, where higher formations rest on disturbed Hudson strata, is due to the erosion which followed the late Ordovicic or early Siluric folding of the eastern strata and which occupied all of early Siluric time.

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[23] Geology of Pennsylvania, vol. i, p. 128.

[24] J. P. Lesley: Summary, First Report Geology of Pennsylvania, vol. i, pp. 663-665.

If we turn now to the easternmost ridges, we find that the Bald Eagle is absent in the Blue Mountain Ridge on the Susquehanna above Harrisburg, where red beds, followed by Tuscarora sandstone, rest on the Hudson River series, which apparently is slightly disturbed here (see beyond). These Hudson beds themselves are rather hard, though as a rule thin-bedded sandstones alternating with shales, in which repeated search has as yet failed to reveal fossils. That these sandstones are the stratigraphic equivalents, in part at least, of the Bald Eagle seems most probable, unless there is more of a hiatus here than we at present suspect. They are more arenaceous in texture than the Utica shales which underlie the Bald Eagle and rest on the Trenton in the Bald Eagle Ridge.

Southward, throughout eastern Perry and Franklin counties, Pennsylvania, the Bald Eagle formation is absent. The Upper Ordovicic of these sections in general begins with the Martinsburg shale series, together with some of the underlying calcareous beds referred to the Trenton.[25] The shale here replaces very largely the Trenton limestone, including in its lower portion fossils of this horizon, while its upper part corresponds, according to the determinations of Ulrich, to the Utica and Lorraine of the New York section. In the Mercersburg region, Franklin County, the Martinsburg shale is 2,000 feet thick, the lower 800 feet consisting of a black, fissile shale, closely resembling the Utica shale of New York and carrying calcareous layers at the base, while the upper 1,200 feet is "sandy and calcareous, with locally hard siliceous beds, and grades upward into ferruginous sandstones referred to the Juniata formation."[26] The upper beds are also coarser, massive, and arkosic. The upper part of the Martinsburg series is sufficiently arenaceous to be classed as a sandstone, and is separately mapped as such in the Chambersburg quadrangle, where its thickness is 600 feet. It is here exceptionally hard, coarse-grained, thick-bedded, and easily recognized. "This rock where fresh is a greenish gray arkose, composed of grains of sand and feldspar; the latter has been decomposed to kaolin, giving the rock a speckled appearance. Toward the base it is interbedded with shale and merges into the shale below."[27] "In coarse, brown sandstone near the top of the formation large *Plectambonites, Rafinesquina squamula,* and *Zygospira modesta* were obtained, and in massive mottled yellowish green sandstone merging into the overlying Juniata formation poorly preserved *Rafinesquina alternata* were found."[27] These faunas are correlated by Ulrich with the Eden of Cincinnati and the Lower Lorraine (Frankfort) of New York. I desire to call attention to the fact that the upper beds are arkoses, indicating semi-arid conditions under which the original rocks from which the sands are derived were disintegrated,* and that this series grades upward into the overlying Juniata red sandstones and shales, the character of which further indicates relative aridity of climate. Stose and Swartz cite Ulrich's opinion that the typical Juniata of Pennsylvania is younger than that of Maryland, Virginia, and Tennessee, which latter he regards as of the age of the Oswego sandstone of New York, while the Juniata of central Pennsylvania is of the age of the Queenston shales (Pawpaw-Hancock Folio, page 4). In his correlation table, Ulrich places the red sandstones of Maryland, Virginia, and Tennessee (Bays sandstone of the latter) even lower, making them the equivalent of the Pulaski shales, and actually placing the Bald Eagle sandstone at a higher horizon. The validity of this assumption may now be considered.

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[25] Upper Chambersburg limestone; see G. W. Stose, Mercersburg-Chambersburg quadrangle. U. S. Geological Survey Folio 170, p. 10.

[26] G. W. Stose and Charles K. Swartz: Pawpaw-Hancock Folio 179, p. 3; see also Mercersburg-Chambersburg quadrangle, No. 170, p. 10.

The basal beds of the sandstone series in the Mercersburg area, where its thickness is 1,200 feet, are a soft yellow sandstone exposed on the Mercersburg pike, 1½ miles southeast of McConnellsburg, and here the following fossils have been obtained by Stose:

1. Segments of undetermined cystid columns
2. *Plectambonites sericeus* (thin small variety)
3. *Lepidocoleus jamesi*
4. *Calymmene callicephalus*
5. *Dalmanella multisecta*

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[27] Stose: Mercersburg-Chambersburg quadrangle, p. 10.

* Marine arkoses are today forming in the Gulf of California, where the local granitic rocks disintegrate under the arid climatic conditions due to the interception of the westerlies by the coast ranges. Decomposition is practically absent, and the disintegrated material is transported by the exceptional sheet floods which occur in this region. (See W J McGee: The formation of arkose. Science, n. s., vol. 4, 1896, pp. 962-963.)

In the ravine below Cowan Gap, a blue fossiliferous calcareous sandstone is exposed weathering into "a soft, porous yellow, fine-grained mudstone." This is regarded by Stose as probably higher in the series than the preceding. It has furnished, besides numbers 3, 4, and 5 of the above list, the following species (Stose, loc. cit.):

6. *Callopora sigillaroidea*
7. *Plectambonites sericeus* (large variety)
8. *Zygospira modesta* var.
9. *Orthoceras transversum* ?
10. *Trinucleus concentricus* ?

In coarse, brown sandstone near the top of the formation besides large Plectambonites (probably number 7) the following were found:

11. *Rafinesquina squamula*
12. *Zygospira modesta*

Finally, in massive mottled, yellowish green sandstone, merging into the overlying Juniata formation, Stose found poorly preserved specimens of:

13. *Rafinesquina alternata*

Analyzing the above meager faunas, we note that *Plectambonites sericeus* ranges from the Stones River to the Maquoketa in the Upper Mississippi Valley, from the Stones River to the Richmond in the Cincinnati region, and from the Trenton through the Lorraine in New York. The barnacle *Lepidocoleus jamesi* has been found in the Upper Trenton beds of the Cincinnati region and ranges through the Eden and through the Maysville. In New York it ranges from the Trenton to the Lorraine. *Calymmene callicephalus,* a form characterizing the lower sandstone beds, ranges from the Trenton to the Richmond in the Cincinnati and Upper Mississippi regions, and from the Trenton to the Lorraine in New York and Canada. *Dalmanella multisecta* was originally described from the lower 200 feet of the Cincinnati beds at Cincinnati, where it is abundant. These represent the Eden horizon of the Cincinnati group, but the species is also found in great abundance in the Mount Hope or Lower Maysville beds of that region. It is also found, though rarely, in the Maquoketa shales of Iowa.[28] The Bryozoan *Callopora sigillaroidea* (Ulrich) (= *C. onealli* var. *sigillaroides* (Nicholson), according to Bassler) occurs in the Eden beds of the Cincinnati region. I have not found it recorded from higher horizons. *Orthoceras transversum* and *Trinucleus concentricus* are doubtfully identified. The first of these was originally described from the Eden beds of the Cincinnati group.[29] The Trilobite *Trinucleus concentricus* occurs in the Upper Trenton limestone of New York, but it is even more abundant in the Pulaski shales occurring, according to Hall (Paleontology of New York, volume I), in the highest beds at Pulaski and Lorraine. *Rafinesquina squamula* James was originally described from the Lorraine (Maysville) beds of the Cincinnati region, where it abounds in the Fairmount bed. Schuchert gives this as the only horizon and locality, but Nickles also lists it from the Southgate or middle member of the Eden.[30] *Zygospira modesta* ranges from the Eden to the Richmond, being also found in the Upper Richmond or Maquoketa of the Upper Mississippi Valley. Finally, *Rafinesquina alternata* ranges from the Upper Black River to the Richmond in the Cincinnati region and from the Trenton to the top of the Lorraine in New York.

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[28] Sardeson's bed 12. American Geologist, vol. xix, 1897, p. 97.

These faunas, therefore, show the series in question to be of Upper Ordovicic age (Trentonian of Grabau), but as to the precise correlation there is very little evidence. Stose cites Ulrich as favoring a correlation with the Eden of the Cincinnati section and the Lower Lorraine (Frankfort) of New York. For such a correlation there is only one species, the Bryozoan *Callopora sigillaroidea,* the others having a wide range. Still we may accept the Eden age of the beds so characterized, but then it appears that this species is found only in the lower (almost the basal) beds of the 1,200 feet of sandstones. This portion might very well be of Eden age, but that does not imply that the upper beds are necessarily so. Indeed, the fossils show that this is not the case. True, all the fossils found are of wide range, but on the whole they are more characteristic of Pulaski than of Frankfort age. If, then, we may consider with Ulrich the lower beds as of Eden age on the strength of a Bryozoan, we may with equal propriety consider the upper beds of Upper Lorraine or Pulaski if not Oswego age on the strength of the brachiopod *Rafinesquina squamula* James, especially since there are no species confined to any other horizon. Furthermore, if the basal beds of a series of strata 1,200 feet thick are of Eden age, the top of that series must certainly be of late Pulaski or Oswego age.

I must here strongly insist on the inadequacy of all such correlation when unsupported by other than fossil evidence. First of all, the range of rare species is by no means established, and, secondly, we have abundant evidence that species confined to certain horizons in one locality may transcend that horizon in another. In the present case, Ulrich's correlation of the upper beds with Eden is unsupported by fossils and by other stratigraphic evidence, to be noted presently, while my correlation of these beds with Upper Lorraine is not only supported by fossils, but is rendered next to imperative by the relationships of the strata.

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[29] S. A. Miller: Cincinnati Quart. Jour. Sci., vol. 22, p. 129.

[30] J. M. Nickles: The geology of Cincinnati. Jour. Cincinnati Soc. Nat. History, vol. xx, No. 2, pp. 49-100.

The post-Trenton rocks of the region between Utica and Watertown comprise at the base the Utica shale, about 600 feet thick, the Frankfort shale, and the Pulaski shale, the two together constituting the Lorraine group. Above these comes the white Oswego sandstone, which has a thickness on the Salmon River of about 110 feet, and at Oswego is succeeded by the red beds. There is no break in the series of strata from the Trenton to the Oswego, each grading into the other. Ulrich, to be sure, separates the Trenton and Utica of this region (north central New York) by a break, but this is an absolutely unwarranted proceeding and evidently done to fit a theoretical scheme of correlation, which has no sound basis in fact.

Observation after observation shows that the Trenton and Utica are formations representing continuous deposition. The evidence is absolutely conclusive that the Trenton type of sedimentation is gradually replaced by the Utica type. Indeed, the Utica type of mud began while Trenton conditions were still dominant—that is, while in the main the organic limestones were accumulating, the black muds repeatedly invaded the region of such deposition, this resulting in the formation of intercalated layers of black shale between the limestone beds. The shales commonly contain the Utica graptolites and the limestone the Trenton fauna. As I have repeatedly stated, the black mud phase which constitutes the Utica shale of Utica and of the region to the northwest is merely an eastern mud phase of the Trenton type of deposition, which was organic limestone. Eastward the mud deposition began earlier; the black shales are thicker and the limestone thinner. The black muds have, of course, their distinctive fauna, chiefly graptolites and such trilobites as *Triarthrus becki*. This latter is cited by Ulrich from the basal 10 feet of the Martinsburg shales. I have elsewhere stated that I regarded the Lower Martinsburg shale of eastern Pennsylvania as the mud equivalent of the Trenton limestone of Pennsylvania, and I may reiterate here that I consider the lower 800 or 1,000 feet of the Martinsburg, which lithologically has the character of the Utica, the real Utica in the wider sense of the term, namely, that it is the black mud facies which in central Pennsylvania (Center County, etcetera) is represented by Trenton limestone and thin shale. In the same way I consider the Lower Utica shale and intercalated sandstones of the eastern part of the Mohawk Valley, now called the Canajoharie shale, the stratigraphic equivalent of the Trenton limestone of the type section. That this shale contains some graptolites not found in the higher horizons is to be expected. The following species seem to characterize these lower beds, according to Ruedemann:[31]

1. *Corynoides curtus* Lapworth
2. *Glossograptus quadrimucronatus* (Hall)
3. *G. ? eucharis* (Hall)
4. *Lasiograptus bimucronatus* mut. *timidus* Ruedemann
5. *Climacograptus putillus* (Hall)
6. *Climacograptus typicalis* Hall

The last of these seems to come in somewhat later than the others (Ruedemann).[32] The species listed under numbers 2, 3, and 6, Doctor Ruedemann says (loc. cit., page 34), "the collector meets in almost every outcrop of the typical Utica shale in both Canada and New York." *Corynoides curtus* seems to be one of the graptolites restricted to the lower mud beds which are found only in the eastern area and are represented by limestones westward. That the Upper Utica shale as exposed in the type section and northward is the equivalent of the Upper Trenton limestone westward I have no doubt. Westward the Trenton limestone thickens to 650 feet or more in Oswego County and northward, while the Utica thins to 150 feet at Central Square and 113 feet at Stillwater. At Pulaski the Utica comprises from 100 to 250 feet and at Sandy Creek, Oswego County, from 250 to 300 feet.[33] In western New York the Trenton limestone is, unfortunately, not open to observation, but from its increased thickness and the total diminution of the shale between it and the Oswego sandstone there is every reason for believing that a westward replacement of the shale by limestone takes place, and that the black muds succeeding the limestone in western New York are the Lorraine shales, which here have a Utica facies, expressive of the westward migration of the zones of deposition, with the shoaling or emergence eastward. As further confirmation of the soundness of the correlation of the Utica shale of the Appalachian trough (including the eastern Mohawk region) with the limestones forming on the margin of the Canadian shield, we have the occurrence of the characteristic Utica graptolite *Climacograptus typicalis* in the Middle Galena (*Fusispira* and *Nematopora* beds) at Mantorville and Weisbachs Dam near Spring Valley, Minnesota.[34] The

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[31] Graptolites of New York, part ii, p. 37.

[32] See also N. Y. State Museum Bull. 42, p. 519 ff.

[33] N. Y. State Museum Bull. 30, pp. 456, 449, 442, 437.

[34] Winchell and Schuchert: Paleontology of Minnessota, p. 82.

Utica mud phase also extended westward to Cincinnati, where the Fulton shale, from 1 to 26 feet thick and carrying *Triarthrus becki,* represents the last of the Trenton-Utica horizon.

Measurements of the thickness of the Lorraine (Frankfort-Pulaski) beds of the third New York district are obtained by subtracting the estimated thickness of the Utica from the total thickness of the shales between the Trenton and the Oswego sandstone. This in Central Square, Oswego County, is 729 feet, leaving 579 feet for the Frankfort and Pulaski, the lower 100 feet of this being passage beds. At Oswego the total interval is 597 feet, and at Stillwater it is 643 feet, leaving 530 feet for the Frankfort-Pulaski. In Pulaski 500 feet of such shales occur, of which the lower half or less is Utica. In western New York the shales between the Trenton and the Oswego have a thickness of 598 feet at Rochester, where the Trenton is 954 feet, and 630 feet at Buffalo, where the Trenton is 720 feet, and these, as above noted, probably represent largely the Lorraine series of the third district, though of a facies more like that of the Utica. The thickness of the Trenton limestone of the Georgian Bay section from the point where it rests on the gneiss to Collingwood, where it passes beneath the "Utica" shale, has been estimated at 900 feet,* though Logan says that "it is not unlikely that the strata may be affected by very gentle undulations, and it would therefore be scarcely safe to state the amount at more than about 750 feet." [35] Even if this latter estimate is the correct one, it must be remembered that the basal beds of the Trenton are probably absent by overlap, since the limestone rests directly on the gneiss. The well known "Utica" beds at Collingwood and Windsor are characterized by a great abundance of *Asaphus canadensis,* together with *Triarthrus becki, Plectambonites sericeus, Rafinesquina alternata, Dalmanella testudinaria,* and *Rhynchotrema increbescens.* At Collingwood the rock is a dark, brownish black shale, interstratified with occasional beds of compact, brownish limestone, the shale being very high in bituminous matter. Higher up the beds are "bluish gray argillaceous shales, inclosing beds of calcareous sandstone, sometimes approaching to a limestone at irregular intervals and of variable thickness." [36] Flagstones also occur in the series. These higher beds contain a typical Lorraine fauna, including *Cyrtolites ornatus, Byssonichia radiata,* and *Modiolopsis modiolaris.* Associated with these are graptolites identified as *Diplograptus pristis.* The whole thickness of the deposit is shown near Collingwood, where some 770 feet of these beds overlie the "Utica" shales above mentioned. These can be traced northeastward to the Great Manitoulin Islands, where their thickness is not over 50 feet. The highest beds of the "Hudson" series contain *Columnaria alveolata,* and with this, on the islands northwest of Cabots Head, is associated *Beatricea undulata.* These fossils are good indicators of the Richmond age of these higher beds, for in the Ohio region Beatricea does not appear until the base of the Liberty beds, while the coral occurs in the uppermost Richmond (Madison or Elkhorn bed).[37] Both forms have a similar position in the Upper Richmond of Anticosti.

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* P. E. Raymond has recently shown (Bull. Geol. Soc. Am., vol. 24, p. 111) that the highest Trenton strata of western Ontario are younger than the typical Trenton beds of Trenton Falls, N. Y., which is a direct corroboration of my stratigraphic determination.

[35] Loc. cit., p. 193.

[36] Logan, p. 212.

Overlying these Richmondian beds on the Indian Peninsula are red and green shales, originally referred to the Medina. In the vicinity of Cape Commodore they are 109 feet thick and are followed by about 36 feet of thin-bedded magnesian limestone, referred to the Clinton, above which comes the Pentamerus bed of the western New York Clinton. At Cabots Head, where the dolomites are 26 feet thick, and at Owen Sound, where they are 20 feet thick, they contain *Leptæna rhomboidalis, Dalmanella* cf. *testudinaria, Stenopora fibrosa* Billings (= ? *Eridotrypa trentonensis* (Nicholson) [Foord], a Trenton species), *Strophomena pecten* (= *Schuchertella subplana*), *Orthis davidsoni, Anoplotheca planoconvexa, Favosites gothlandica,* and others. This is a basal Siluric fauna similar to or earlier than that found in Wisconsin. Overlying these dolomites at Cabots Head are "103 feet of red marly sandstones, partially striped and spotted with green, and interstratified with beds of red and green argillaceous shale, some of which exceed 6 or 8 inches in thickness."[38] The green argillaceous beds appear to be free from calcareous matter. The series is followed by about 55 feet of green calcareous-argillaceous shales and thin-bedded limestones, and terminated by the massive limestone of the Niagaran series, which, here as elsewhere in this part of Canada, begins with the Pentamerus bed, equivalent to the Walcott limestone of New York. *Helopora fragilis,* which abounds in the lower true Medina at Niagara and in the Clinton iron ore at Rochester, also occurs in an impure hematite bed in the upper red beds. *Ptilodictya* (*Phænopora*) *explanata,* another Clinton form, also occurs here.

As will be more fully shown later on, there is excellent reason for believing that the lower 109 feet of red and green shales resting on the Richmond of the Indian Peninsula represent the westward extension of the Queenston shale. According to Foerste,[39] these red beds rest on successively higher Richmond beds northwestward in the Manitoulin Islands. The upper 103 feet of red marly sandstones of Cabots Head will likewise be shown to be Upper Medina, which is thus included as a wedge in marine Clinton.

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[37] J. M. Nickles: Richmond Group in Ohio and Indiana. American Geologist, vol. xxxii, p. 213 (202-218).

Schuchert: Paleogeography of North America. Bull. Geol. Soc. Am., vol. 20, p. 530.

[38] Logan: Geology of Canada, 1863.

Returning to New York, we find the Oswego sandstone capping the Hudson series. At Niagara this sandstone is 75 feet thick and westward of this it soon disappears.

Near the eastern end of Lake Ontario and on the Salmon River this sandstone is well shown in many exposures. On the Salmon River above Pulaski, where it forms the fall 107 feet in height, its thickness somewhat exceeds the height of the fall. It here rests on the Lorraine shales and appears to grade down into them, thus indicating that they form with this shale a continuous depositional series. Fossils are rare in this rock, but they have been found[40] and indicate that these sandstones were in part at least submarine. Trails and impressions of the type generally referred to as fucoidal are common in certain layers. Irregularity of bedding is another feature shown in these sandstones, while in some sections the sandstone is seen to contain shale lenticles, which represent broken layers of lutaceous sediment subsequently incorporated in the deposits of sands. These features indicate that the water in which these deposits were forming was very shallow, and indeed much of the material suggests subaërial rather than a submarine origin.

In attempting to trace the source of the material composing the Oswego sandstones, we must first carefully consider the nature of the material itself. Nearly pure quartz, such as makes up this deposit, must have its ultimate source in some crystalline quartz-bearing formation. It is true that such a source need not be a direct one, for an older quartz sandstone may be reconstructed, thus becoming the direct source of the material. We must then look for an older sandstone or a crystalline area as the source of the material. The nearest crystalline area to the present outcrops is, of course, the Adirondack old land, and only a little farther removed we find the crystallines of the Canadian shield. If either or both of these deposits were the source of the material of the Salmon River (Oswego) sandstone, it is to be regarded as a remarkable fact that the material is so thoroughly assorted and of so uniform a grain, considering the nearness of the source of supply. One might, of course, cite the Potsdam sandstone as an example of a pure quartz sandstone resting on an old land of crystalline character, from the disintegration of which it was apparently derived, but that is hardly a good analogy, since the Potsdam sandstone represents residual quartz most probably reworked during an enormous length of time (the whole Cambric and perhaps a part of Algonkic time) by both wind and water, until all the decomposable material had been removed before it was finally buried as an Upper Cambric (Lower Ordovicic) sandstone. But during Lorraine time the Adirondacks and the Canadian region had no such accumulated material, as is shown by the fact that pure limestones like the Trenton were forming in the immediate vicinity of the crystallines, and in some cases, as at Kingston Mills, Ontario,[41] and elsewhere, rested directly on the smooth floor of crystalline rock. Indeed, there is good reason for believing that the greater part of the Adirondacks, if not the whole of them, were covered by Trenton limestone and later deposits, and that these were not removed until the end of Siluric time. The Canadian shield likewise seems to have been covered to such a degree that it could hardly have furnished clastic material for such a sandstone.

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[39] Geol. Soc. Am. Washington Meeting, preliminary outline of papers.

[40] L. Vanuxem: Report on the Third District, New York, p. 69.

If these conclusions are correct, there seems to be no other source than the Appalachian old land for these sandstones, and indeed they or their New England extensions must have furnished the sand and mud for the Hudson River clastics throughout, since the Adirondack and Canadian areas permitted the simultaneous deposition of calcareous sediments. This is shown by the fact that around these old land-masses the deposits of the whole lower and middle, as well as part of the Upper Ordovicic, are calcareous, while to the southeast they are replaced by the siliceous deposits forming the Hudson River group.

If we admit the Appalachian source of the Oswego sands for the eastern region, we must admit it for western New York as well, and, for the same reason, we must connect these sandstones with the Bald Eagle fan. For such a deposit of pure sands calls for a corresponding, though not necessarily, as pure a deposit nearer to the source. It is also logical to assume that such a deposit should become coarser and thicker as we approach the source of the material. There is no sandstone or conglomerate in the Appalachians which fits these requirements and is at the same time of the corresponding age except the Bald Eagle. Even if we regard this formation as a submarine delta deposit, against which interpretation all its characteristics protest, we must consider that the lower part of the series is of less areal extent than the upper, for this is true of submarine as well as subaërial delta deposits, and so we come to the inevitable conclusion that the Oswego sandstone of New York represents the higher beds of the Bald Eagle deposit. The lineal distance between the two regions is not over 160 miles, which is not excessive for such deposits.

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[41] A. W. G. Wilson: Canadian Record of Science, vol. ix, No. 2, 1903, p. 129.

Going northeastward into Canada, we find that (Logan, page 198) in the Montmorency region east of the city of Quebec the post-Trenton shales are 1,114 feet thick in a measured section on the River Saint Anne, and may reach a total of 2,300 feet. Only the lower 318 feet of these strata are referred to the Utica. They are conformable with the Trenton limestone, the upper beds of which show intercalated shales of the Utica type and grade upward into the Utica shales. *Lingula* ? and *Diplograptus pristis* are the only fossils recorded from these shales. The shales also grade upward into sandstones and arenaceous shales with *Plectambonites sericeus* and *Dalmanella testudinaria,* with a total thickness of 719 feet. These beds contain occasional black bands, but for the most part are grayish or greenish arenaceous shales, with occasional conglomerate beds. They apparently represent Lorraine, to which horizon they were referred by Logan.

The uppermost division is again a black shale, containing *Climacograptus bicornis* and *Dicranograptus ramosus* as well as *Triarthrus becki.* If there is here no repetition by faulting and if the identifications are correct, we have a remarkable recurrence of the Utica fauna, with the recurrence of the Utica type of shale above beds of Lorraine age.

These higher black shales of the Quebec region may even represent the Richmond horizon. Near the Little Rivier du Chêne, on the south side of the Saint Lawrence, the beds contain *Plectambonites sericeus, Rafinesquina alternata,* and *Dalmanella testudinaria,* and are succeeded by red shales, "which appear to overlie them conformably" and probably represent the Queenston horizon. In the vicinity of Saint Grégoire, Quebec, the upper beds contain *Stenopora fibrosa, Plectambonites sericeus, Rafinesquina alternata, Dalmanella testudinaria, Hebertella occidentalis, Catazyga headi, Rhynchotrema capax, Pterinea demissa, Orthoceras crebiseptum,* and *Asaphus platycephalus.* If these identifications are correct, the fauna would appear to be of Richmond age. The beds are succeeded by red shales, presumably of Queenston age. Northeastward in the Anticosti region no such red sediments terminated the Ordovicic series, but normal marine conditions continued into the Siluric.

Comparing the Lorraine-Oswego beds of the third and fourth New York districts with the Upper Martinsburg of southern Pennsylvania, it appears that the latter, representing Eden (Frankfort) and Maysville

(Pulaski), is more than twice as thick as the Frankfort and Pulaski of New York. It seems more than likely that the Oswego sandstone of the south shore of Lake Ontario was also deposited during Upper Lorraine time, and is to be included with the Pulaski and Frankfort beds in that division. Northward in the Quebec region, as we have seen, this sandstone is absent and the Upper Hudson beds are of Richmondian age.

The influence of the currents bringing the quartz sands of the Oswego was evidently not felt in the Quebec region, where continuous deposition went forward. From this fact, and the general character of the beds in the Saint Lawrence, it is safe to argue that the Adirondack old land was not exposed, but covered to a greater or less degree by the Lorraine-Utica strata, as well as the Trenton limestones beneath these. The abundant fragments of Trenton and Beekmantown limestone scattered over parts of the region further indicate the former presence of a covering of these rocks.[42]

Summary history of the Bald Eagle delta.—If we now correlate all the facts so far ascertained with reference to the closing deposits of the Ordovicic in eastern North America, we find that the Bald Eagle conglomerate of central Pennsylvania is best explained as a coarse pebble and sand delta of subaërial origin, built by a large stream from the old land to the southeast into the Upper Ordovicic Sea which covered the present Appalachian region. The debouchure of this stream was in the neighborhood of Tyrone, Pennsylvania, as shown by the great thickness of the deposits there. The upstream continuation of this delta has partly been removed by erosion and in part it is concealed by faulting. The delta was perfectly conformable with the underlying Hudson strata of earlier age, and represents merely the local accumulation of coarse river sediment brought by a revived stream from the rising highlands on the southeast. Other similar streams no doubt existed and their deposits gave rise to the coarser beds occasionally found in the Upper Hudson series, but none seem to have been so pronounced. My belief is that this delta-building commenced in Upper Eden (Frankfort) time and continued through Lorraine or until the Pulaski shales and Oswego sandstone were deposited. The latter, indeed, must represent the upper part of the Bald Eagle, the most extensive (areally) of the overlapping beds of the series. The close of the building of this delta probably fell in late Maysville time, but before the end of that epoch. In the east the end of the Maysville epoch was inaugurated by red sedimentation, which continued through the greater part of Richmond time. Marine deposition continued to the north, as shown by the Lorraine and Richmond beds of Quebec, to the west, as shown by the presence of the Lorraine and Richmond faunas in a continuous sedimentation series (Hudson) in the Lake Huron region, and to the south, as shown by continuance of the Sevier shale of Virginia and Tennessee into the red Bays sandstone overlying it. Ulrich in his correlation tables[43] makes the Bald Eagle the exact equivalent of the Oswego sandstone without giving reasons for this correlation.

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[42] See Ida H. Ogilvie: Paradox Lake quadrangle. Bull. 96, N. Y. State Museum, p. 467. This is also held by Cushing. (See N. Y. State Museum Little Falls Bulletin.)

Aside from the fact that a formation of sandstone over a thousand feet thick in one section can hardly be the exact equivalent of another bed of similar sandstone only 100 feet thick, we have shown that in the east the sandstone begins earlier and rests on lower beds than in the northwest. In Bald Eagle Mountain it rests on lowest Pulaski, if not Frankfort; in the Buffalo and Pulaski region it is post-Lorraine.

The probable extent of this fan must have rivaled that of the Huang Ho or Yellow River of China of today. Not counting the Appalachian folds, the distance from the easternmost outcrop to its disappearance in the northwest is more than 200 miles. Add to this the amount of its former eastward extent, removed by comparatively early Siluric erosion, and we get in the neighborhood of 250 or 300 miles as the radius of the fan. Of course, this radius was not necessarily the average radius. It seems far more likely that the deposit was a long and relatively narrow one. No doubt, too, some of the material of this delta was removed and redeposited during the succeeding period of red sedimentation, which seems to have followed almost without change in the relative position of land and sea, except perhaps an increased elevation of the mountains supplying the sediment on the east, as will be more fully explained after the character of these deposits has been considered.

A fact of interest in this connection is the finding of remains of Eurypterids in the Trenton shales of New York. Good specimens have been found in the Schenectady shale of the Mohawk Valley by the New York State Survey, but though they are well preserved no entire specimens have been discovered. They are associated with graptolites to be sure, but the beds in which they occur also contain mud cracks,[44] and apparently represent a surface swept over only occasionally by the sea, which spread seaweeds and graptolites over it as seaweeds and hydryoids are spread over our mud flats at the present time.

The possibility that the Eurypterids were swept into this area by the river waters from the Appalachian land must not be overlooked. The Oswego sandstone is absent here, removed by early Siluric erosion, which also removed the whole of the Pulaski shales. But a little to the north these formations occur in their full strength, and, as we have seen, the material of which they are made could only have come from the Appalachians. If the Eurypterids were river animals at this period of the earth's history, as they certainly were in later Paleozoic time, it is not improbable that their remains will be found in the finer deposits of the Bald Eagle delta. Eurypterids are said to occur in the Eden of the Cincinnati region,* and these specimens may have a similar origin, being floated into the shallow waters of the interior, as we know that today terrestrial organisms are carried out for hundreds of miles from shore. Of course, the possibility that Eurypterids were marine organisms during this period of the earth's history must be conceded, but the evidence for this is to my mind not very strong. This subject will be more fully discussed in a later section of this paper.

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[43] Bull. Geol. Soc. Am., vol. 22, No. 3, pl. 27, opp. p. 608.

[44] Private communication by Doctor Ruedemann.

Schuchert[45] correlates the Upper Lorraine (Pulaski) of New York with the Mount Hope and Fairmont beds of the Maysvillian, which would make the Oswego the equivalent in time of the Bellevue and perhaps Corryville zones. This seems a sound correlation so far as the typical Lorraine strata of the third New York district are concerned. Northward in Quebec, however, the "Hudson" beds rise higher, being equivalent to the whole of the Maysville and a part of the Richmond as well. Southward in southern Pennsylvania the Martinsburg shale includes the whole interval from near the base of the Trenton to probably Bellevue or Corryville of the Upper Maysville, inclusive, or, in other words, the Upper Martinsburg is the equivalent of the Lorraine and Oswego. Westward the top of the "Hudson" series likewise rises, being post-Maysville in the Lake Huron region, where typical Richmond fossils occur in the higher beds. In the stratigraphic depression thus left by the rise in the horizon of the top of the "Hudson," northward, westward, and southward, lies the Bald Eagle delta, a continental deposit, the base of which rises in proportion and in the same direction as the top of the underlying Hudson, its marine equivalent, rises. The overlap of these delta beds is thus a replacing one away from the source of supply, which was in the older Appalachian land toward the east. The following diagram (figure 4) shows the general relation of these strata.

The Juniata and the Queenston red beds.—The Juniata formation was named by Darton from its typical development along the Juniata River in Pennsylvania. It is the "Red Medina" of the second Pennsylvania survey, though under this name was also included the Longwood (Salina) shale of the eastern monoclinal or Blue Mountain-Kittatinny Mountain Ridge. Another local deposit of red rocks, the true Medina, was also included here. In western New York occurs a great series of red shales and sandstones, which at Niagara, where they underlie the white Whirlpool quartzite and rest on the Oswego sandstone, have a thickness of 1,142 feet. These shale beds have generally been called Lower Medina, and included with the Oswego sandstone below and the Whirlpool sandstone, the Medina sandstone and shales and the upper gray or *Thorold* sandstone above, in the Oswegian group, which was made the base of the Siluric. These lower shales I have recently renamed the Queenston shales from their exposure at Queenston on the Niagara River, and have referred them to their true position as the equivalent of the marine Richmond deposits elsewhere.[46] These shales and sandstones are to be regarded as the westward extension of the Juniata beds of Pennsylvania, and they were unquestionably derived from the Appalachian region, since, as I have already shown while discussing the origin of the Oswego sandstone which underlies them, there is no other adequate source from which such material could be supplied.

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* Private communication from Mr. Ulrich.

[45] Bull. Geol. Soc. Am., vol. 20, Paleogeography of North America, p. 530.

It is now perfectly well understood that the red color of a series of clastic sediments of this type is due primarily to peculiar climatic conditions which

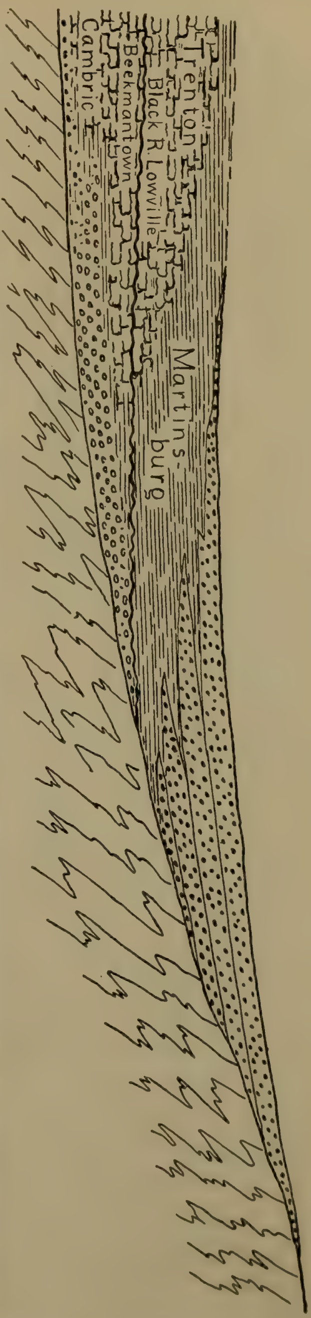

FIGURE 4.—*Diagram showing the Bald Eagle Delta Deposits (subaerial) on the East, Replaced westwardly by Martinsburg (Hudson) Shales, which in turn merge Westward into and are Replaced by Limestones*

permitted extensive oxidation of the iron compounds in the sands and the rock-floor while they were being transportated or during and after deposition. Studies in desert regions have shown that such oxidation is extensively carried on under arid climatic conditions, with a depressed water table and a scarcity or absence of vegetation. That oxidized beds can be contemporaneous with white, gray, or even black non-oxidized beds admits of no doubt, nor that one may merge into the other. Such oxidized beds are not always red at the time of their formation. Indeed, it is more likely that oxidation is always accompanied by a certain amount of hydration, the result being an ochery or yellow tint. Dehydration and the corresponding change to a red color is, as shown by Crosby, a process of ageing, and may take place subsequent even to burial of the oxidized strata.[47] Now, it can only be an exceptional and peculiarly local series of conditions, which will permit extensive oxidation away from the source of supply, while near it no such oxidation occurs. It is scarcely conceivable that river-spread sediments over a broad emerged area at the foot of a highland region should fail of oxidation in the first 100 miles of their area of sedimentation, but be thoroughly oxidized throughout a thickness of over 1,000 feet in the second belt or a distance of 200 miles from the source. Rivers may perhaps carry sediment from a region of oxidation, through a region where vegetation prevents such oxidation and deposit them beyond this point as oxidized sediments, but in any case the region from which the supply is derived is the chief one to suffer oxidation.

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[46] Science, n. s., vol. xxvii, 1908, pp. 622-623; vol. xxix, 1909, pp. 351-356.

If these conclusions are sound, we must consider that the red Queenston shales of the Niagara region are contemporaneous with the red sediments of the Appalachian region, unless we assume that the former are a secondary deposit, the material being derived from the erosion of the older beds. Against such a supposition, however, the relative uniformity of lithic character of the Queenston beds, their thickness, and especially their uniform color, as well as their relation to the inclosing rocks, form a strong argument. A further argument that the beds of western New York were deposited under conditions of aridity is shown by the occurrence in them of saline waters, this being, indeed, the lowest saliniferous horizon of western New York. I believe that there can be no question but that the Queenston and Juniata are contemporaneous sediments. It is, of course, true that red sedimentation* began earlier in the Appalachians and progressed outward by overlap. Nor is the upper surface of the red sediments of the Appalachians at the exact horizon of the upper level of the red Queenston shale, for both have probably suffered erosion before the deposition of the succeeding beds. Essentially, however, they are to be regarded as contemporaneous.

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[47] For a full discussion and citation of literature see Barrell. Bull. Geol. Soc. Am., vol. 23, p. 416 et seq. Also A. W. Grabau: Principles of Stratigraphy, A. G. Seiler & Co., 1913.

* By this term is to be understood the deposition of oxidized sediments, which subsequently may by dehydration assume a red color, and not that the sediments were necessarily red at the time of formation.

What has been said of the contemporaneity of the red beds of the Appalachians and western New York applies with equal if not greater force to the red beds of the Appalachian region itself. Ulrich thinks that there are two red series in the Appalachians. He would make the "Juniata" of southern Pennsylvania and Maryland, as well as the Bays of the southern Appalachians, of earlier age than the Juniata of the western ridges. I have shown in the preceding pages that the stratigraphic evidence is wholly against such an interpretation in the southern Pennsylvania region, where only a false identifications of horizons could lead to such a supposition. I have, I believe, definitely shown that the Bald Eagle horizon is there represented by the upper marine Martinsburg sandstones, the upper part of which is of late Lorraine and Oswego age. Hence the succeeding red beds are Juniata. As for the Bays sandstone, I also have paleontological evidence that Ulrich's supposition is incorrect. This will be given further on. If Ulrich's supposition were correct, we would have in the eastern region first red sedimentation, then a great series of white and gray sediments, followed again by red sedimentation. That such is not the case is shown by the fact that nowhere in the immediate vicinity of the so-called older red series, nor away from it, is there any indication of red sedimentation beneath the Bald Eagle conglomerate, even though the distance is only a few score of miles. It is inconceivable that if red sedimentation went on near by there should be no trace of such sediment wherever the white conglomerate and sandstone appear except above it. This can only be interpreted as indicating that red sedimentation followed, but did not precede the sedimentation of the white sand and pebbles, and that wherever the white beds as such are absent and there is no hiatus they are represented by marine sands and clays on which the red beds come to rest. In other words, the red beds overlap the continental portion of the white beds and rest directly on the marine equivalents of the latter. Thus we conclude that there is only one Ordovicic red series in Pennsylvania and Maryland, namely, the Juniata formation.

If we now consider the principal sections in eastern and central Pennsylvania and adjoining regions in which the Juniata beds are exposed, we find considerable variation in the thickness of the deposit at different points. Beginning again in the westernmost ridges, we have the most southern exposure of this rock in the gorge of Wills Creek, where it cuts through Wills Mountain just northwest of the city of Cumberland, Maryland. I examined this small exposure in the center of the anticline in 1910, but could not wholly satisfy myself of the relation of this to the succeeding rock. It is not improbable that these red beds are post-Juniata, or of Siluric (Medina) age, representing the reworked Ordovicic Juniata, as will be more fully discussed further on. The fact that the formation apparently grades upward into the overlying Tuscarora at this point lends additional weight to the supposition that all of the red beds shown may not be Ordovicic. Nevertheless, it must not be overlooked that even if there is a hiatus between the two series of beds, as would apparently be the case if the lower bed is true Juniata, the expression of this hiatus may be obscured by the reworking of a part of the upper beds at the beginning of Tuscarora sedimentation.

The red beds of the Wills Gorge section are interbedded sandstones and shales, the former usually of slight thickness, though some of the sandstones are over a foot thick. Clay galls and flattened clay pebbles either red or green occur in some of the sandstones, and cross-bedding of the torrential type is seen in some of the higher beds. Lutaceous material predominates, some of the shale beds being 6 feet or more in thickness. Both shales and sandstones are more or less micaceous in character. The total thickness measured by the Maryland Survey[48] is 530 feet, though 140 feet is covered by talus.

Farther north in the Wills Mountain Gap at Milligans Cove in Bedford County, Pennsylvania, 800 feet of the red sandstone are shown resting on 100 feet of Bald Eagle. According to Rogers,[49] the formation here contains more gray sandstone than usual. Throughout the Bedford County district the Juniata "contains comparatively little soft shale, its beds being chiefly hard, fine-grained red sandstone grits." Clay galls and compressed clay pebbles are common, these usually being of an ochery color and of such a condition as to easily weather out, leaving the rock in a honeycombed condition. In other cases these clay galls are red in color. As already mentioned, these sandstones overlap the Bald Eagle in the southern part of Bedford County, where, in the sections made by the Juniata through Tussey and Evitts mountains, these red beds rest directly on Upper Martinsburg sandstone and shale (here of Oswego age) and form a continuous depositional series with it. Professor Stevenson here found fossils which he identified as *Ambonychia* [*Byssonychial*] *radiata* and *Rhynchonella capax*. The latter has been identified by Ulrich as *Orthorhynchula linneyi*. I have not seen these specimens, but I venture the query whether these specimens may not be small forms of the short-hinged gibbous *Platystrophia lynx* (*ponderosa* Foerste) var. *stevensoni* Grabau. Undoubted specimens of this species are found associated with *Byssonychia* of the *richmondensis* type in the Bays sandstone of Tennessee, where I have collected them at Walker Mountain. Since the fossils of the red sandstones are all molds (internal as well as external), small specimens of the *P. stevensoni* may easily be mistaken for *Orthorhynchula linneyi* or for *Rhynchotrema capax*. On the basis of the distribution of the fossils at Cincinnati, the Orthorhynchula would indicate the Fairmount beds in the Lower Maysville, while the *Platystrophia lynx* (*ponderosa*) would indicate the Mount Auburn or highest Maysvillian. According to Schuchert's correlation, this would in the one case be late Lorraine, in the other post-Lorraine and post-Oswegon as well. I am satisfied that the latter is the correct correlation, even should the fossils from Bedford County prove on critical examination to be Orthorhynchula. *Byssonychia radiata* ranges through the Lorraine and the Richmond and so is not of value in precise correlation. It is probable, however, that the species is not *radiata* in the restricted sense, but belongs to the richmondensis group, as is the case with the species from Walker Mountain.

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[48] Alleghany County, p. 87.

[49] Geology of Pennsylvania, p. 129; see also Stevenson Report T_2.

The Blair County sections[50] of the Juniata also show an alternation of shales and sandstones. In Tyrone Gap, where a good exposure of this and the enclosing formations are found, the section comprises the following beds in descending order:

	Feet	In.	Feet	In.
33. White sandstone	100 +		100 ±	
Possible base of Tuscarora.				
32. Red sandstone, with layers of red shale from 6″ to 5′ thick	255			
31. Concealed interval	540			
30. Red massive sandstone	84			
29. Green slaty sandstone	1	8		
28. Red sandstone with a few layers of red shale	87			
			967	8
27. Green slate	0	6		
26. Red sandstone	10			
25. Red shale	5			
24. Green slate	5			
23. Red sandstone	5			
22. Gray sandstone	20			
21. Red shale	1			
20. Gray sandstone	10			

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[50] Report T on Blair County by Franklin Platt, 1881, pp. 17 and 47; also Report T_3, p. 144.

	Feet	In.	Feet	In.
19. Red shale	0	6		
18. Red sandstone	10			
17. Grayish red sandstone	15			
16. Red slate	1			
15. Green slate	1	6		
14. Gray sandstone	15			
13. Gray slate	1			
12. Brown sandstone	20			
11. Gray slate	1			
10. Brown sandstone	8			
9. Red shale	0	6		
8. Reddish brown sandstone	75			
7. Red slate	1			
6. Red and gray sandstone	200			
5. Red sandstone and shale, alternating with some green shales and brown sandstones	112			
			518	
Base of the Juniata series.				
4. Brown and gray sandstones and concealed members	150			
3. Gray sandstone and concealed members	409			
2. Gray sandstone	320			
1. Gray and slaty sandstone	440			
Base of the Bald Eagle.			1,319	
Total			2,905	

The sandstones are often markedly cross-bedded, and the alternations here give a good example of rhythmic succession of oxidized and unoxidized strata. If all the red beds of this section are included in the Juniata, this would be 1,486 feet thick. Lesley[51] thinks that the "Red Medina" comprises the lower 518 feet, plus some 400 or 500 feet of the overlying beds, making in all about 1,020 feet, but this would draw the line in the middle of the concealed series (number 31) and would leave a considerable thickness of red beds above this plane. At the base of number 28 there occur some pebbly layers, which may mark a dividing line between a Lower (Queenston) or true Juniata and an Upper (Medina) series, the latter composed of reworked Juniata material. Whether this is so or not has not yet been determined. The red beds are characterized throughout by an abundance of clay galls thoroughly compressed.

At Bellefonte Gap, in Center County, Pennsylvania, the Juniata has, according to Rogers, a thickness of about 500 feet. It is here a "thin-bedded gray and red argillaceous sandstone, alternating with a fourth part red, gray, and greenish shale. High in the mass are found stem-like vegetable forms resembling an irregular *Scolithus*. This appears to be the *Scolithus verticalis* of Hall, a fossil of the Medina sandstone of New York."[52] So far as these tube fillings can be taken as horizon markers, they would indicate the upper beds of this series to be "Medina" and not Queenston.

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[51] Summary Final Report, vol. i, p. 647, foot-note.

In Mill Hall Gap, Clinton County, the series is not well exposed, the beds overlying the Bald Eagle conglomerate consisting of "thin-bedded gray and red clay sandstones, constituting three parts of the whole mass separated by and alternating with beds of red, gray, and greenish shale."[53] The *Scolithus verticalis* has also been found in the uppermost beds. The series is about 700 feet thick and is followed by an equal amount of hard massive red, gray and white sandstones, the Tuscarora.[54] In Lycoming County, finally, the Juniata is reported by Franklin Platt as having a thickness of 1,200 feet, the Tuscarora being estimated at 100 feet, while the Bald Eagle is only 75 feet thick.[55]

Returning to the more southeasterly outcrops, we find an excellent development of the series in Logan Gap, through Jack's Mountain, in Mifflin County, Pennsylvania. The top of the mountain is formed by the great white Tuscarora sandstone, here 820 feet thick, while the Juniata has a thickness of 1,280 feet. It consists of soft, friable reddish sandstones and red sandy shales, the latter commonly showing ripple-marks and mud cracks, while some of the sandstones show marked cross-bedding, apparently of the torrential type. Ten miles southward along the strike, at Orbisonia, in Rockhill Gap through Black Log Mountain, the red beds are 930 feet thick and consist of soft brown and red clay sandstones and shales.

In the Susquehanna Gap through Blue Mountain, above Harrisburg, true Juniata is wholly absent, the few feet of red shale underlying the Tuscarora, which here forms the mountain crest, belonging to the typical Medina of New York, and resting unconformably upon the Hudson beds.

Further south, in Franklin County, Pennsylvania, the Juniata formation, as we have already seen, rests on the upper Martinsburg shale, which passes upward by gradation into the red beds. The lower beds are dull red, cross-bedded sandstones with pebbles and galls of clay shale alternating with bright red shales. Above the lower 200 feet shales are less common, cross-bedded reddish sandstones predominating often with clay pebbles. The thickness varies from 300 to 450 feet, the upper 60 feet or more being massive, cross-bedded, hard purplish-gray sandstones, with thin red shales on top. A massive conglomerate with rounded milk-white quartz pebbles has been found in this part of the formation on Claylick Mountain and on the north side of Cove Gap.[56]

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[52] Rogers, loc. cit., p. 129.

[53] Lesley, loc. cit., pp. 659-661.

[54] H. M. Chance: Report G_4, Clinton County, 1880, p. 120.

[55] Report G_2, p. 29.

Southward in Maryland and West Virginia (North Mountain) the series is only 200 feet thick. At the base is a heavy bed of cross-bedded white sandstone and quartz conglomerate which appears to be local, and is reworked Bald Eagle material. This is followed by coarse reddish sandstones, with some red shales, often containing clay galls.

Northwestward these beds continue under cover of higher formations and do not appear again until the Lake Ontario region is reached, where on the lower Niagara they crop out again. These are the Queenston shales, which have a total thickness of 1,146 feet, and consist mainly of soft red shales, with some sandstones. Only something over 100 feet are shown at Queenston, the lower part being concealed by the waters of Lake Ontario.

Farther toward the northwest we find the basal portion of the red beds rising and apparently resting by overlap on higher and higher members of the Richmond series.[57] The Queenston upper members are seen to rest on the Richmond beds at Cape Commodore, on the Indian Peninsula in Ontario, Canada.[58] These red and green Queenston beds are here 109 feet thick and are followed by 36 feet of lowest Siluric dolomite (Keppel dolomite), above which follow 150 feet or less of red "Medina" shales (Cabot Head beds). This condition can be traced to Cabots Head, on the Manitoulin Islands, but ere long the red beds disappear entirely.

Northeastward the Queenston red beds can be traced to the north side of the Adirondacks, resting, as already noted, on the Upper Hudson shales near Quebec. In the eastern Mohawk Valley they are absent, the Oneida or younger strata resting on the Hudson shales.

The age of the Juniata-Queenston fan or deposit of highly oxidized sands and clays is in part certainly Upper Maysvillian, and in part it is Richmondian. I do not believe that any part of it is early Maysvillian, as suggested by Ulrich.* It is certainly post-Oswego. From analogy with the Bays sandstone, its southern equivalent, the base of this formation must be near the Upper Maysvillian.

Summarizing the characteristics of the Juniata-Queenston, we find it to possess in the main the features of a subaërial deposit. Such an origin is suggested by the red color, which indicates thorough oxidation of the deposit, by the mud-cracks and rill-marks in the shaly beds, by the abundance of clay galls in all of the sandstones, by the cross-bedding of the deposits, which in the coarser beds is of torrential type and in others of the eolian type, and by the irregularity of the sandstone members which locally wedge out, and by frequent evidence of contemporaneous erosion and deposition. Ripple-marks also occur, these, where I have observed them, suggesting an eolian origin. Finally, the general absence of fossils, except where the formation rests upon the underlying fossiliferous strata, with which it forms a continuous depositional series, is certainly significant. The fact that fossils do occur in some of the lower beds shows that there is nothing in this red rock material itself which prevented the existence of marine organisms while it was being deposited and nothing to prevent their subsequent preservation. The presence of these fossils in the lower beds and their absence throughout the upper beds indicates that the lower beds were locally dipping into the sea, but that subsequent withdrawal of the sea from the area of deposition left the higher beds to be deposited as subaërial sediments.*

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[56] G. W. Stose: Mercersburg-Chambersburg Folio, U. S. Geol. Survey.

[57] A. F. Foerste: Geol. Soc. Am. Washington Meeting, preliminary announcement; also Bull. Geol. Soc. Am., vol. 24, March, 1913, p. 110.

[58] Logan: Geology of Canada, 1863, p. 318. The beds are here called Medina.

* Mr. Ulrich has since come to the conclusion that the Juniata-Queenston (Lower Medina) "is equivalent to the greater part, if not the whole, of the Richmond." (Bull. Geol. Soc. Am., vol. 24, 1913, p. 108.) This was my conclusion more than five years ago.

The extensive oxidation of these sand and dust deposits, as well as the general absence of all traces of vegetation, suggest that arid climatic conditions prevailed during the deposition of these beds. The presence of saline springs in the Queenston of western New York tends to confirm this interpretation. Whether winds or streams were the chief agents in the deposition of these oxidized (now red) beds might be a subject for difference of opinion, I am disposed to give the wind a large if not the largest share of credit for the distribution of these deposits, but the confirmation or refutation of such a supposition requires extensive microscopic study of these sandstones which has not yet been undertaken. At the commencement of deposition of these red beds on the previous delta of coarser white quartz sands and pebbles, this latter was to a certain extent reworked, and as a result the contact may in some cases be abrupt; in others more or less transitional. The fact that the beds in western New York have practically the same thickness as those in central Pennsylvania shows that the Juniata was not a new fan built on the Bald Eagle fan, but that it represents in the main the continuance of that deposition which had commenced in Lorraine time, forming the Bald Eagle, only under somewhat different climatic conditions. The same thing is suggested by the fact that the fossils in the basal portion of the red beds, where they overlap the Bald Eagle or rest on its marine equivalent, are of uppermost Maysville types.

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* For a general discussion of the characters of river deposits, see the author's "Principles of Stratigraphy," 1913, chapter xiv. Original structures and lithogenesis of the continental hydroclastics for the characters of eolian rocks, see chapter xiii.

An initial uplift of the old land of Appalachia apparently caused an augmentation of river work, so that instead of fine sands and muds coarser sands and pebbles were brought to the seashore by the rivers and these built up into a delta, a large part of which was of subaërial extent. By the end of the time occupied in the formation of this delta—that is, the Bald Eagle—which was completed toward the end of the Lorraine epoch, the seashore of this region had been pushed northwestward probably to the region of Buffalo and southward to near the Maryland border, while northward it probably lay to the north of the present Adirondacks, then practically non-existent. That over parts of this delta conditions of semiaridity may have at times existed is suggested by the occurrence of red sand and clay layers at one or more levels in the Bald Eagle, but on the whole there seems to have been a sufficient amount of moisture to prevent general oxidation, or at any rate there were stream and wind work enough to wear the quartz fragments into sand and remove other mineral particles which by oxidation and dehydration would essentially produce red beds.

It is difficult if not impossible to conceive of conditions which would bring about such deposition under the present arrangement of moisture-bearing winds. If we conceive of a moderately high, semi-mountainous land on the eastern border of the present North American continent, such as must have existed to furnish all the clastic material piled up in the early Paleozoic formations, and if we further postulate a shallow, but extensive sea lying to the west of this, as is indicated by the widespread deposits of marine Ordovicics, we have, with our present westerly winds an admirable arrangement for extensive rainfall on the western slope of such mountains, but such extensive rainfall would be accompanied by much vegetation, especially if, as seems likely from the nature of the Ordovicic fauna, the sea was a warm one. Such vegetation would, of course, be prohibitive of much torrential or eolian deposition, for the mantle of vegetation would protect the underlying rock from erosion except locally. Such conditions now exist on the western slopes of the Coast Ranges of Oregon, which face the ocean and run at right angles to the direction of the westerly winds. Here the rainfall exceeds 100 inches a year.[59] The eastern side of these mountains, on the other hand, are much drier except where local features are operative. "The great height and continuity of the Sierra Nevada and the Cascades cause these mountains thoroughly to obstruct the westerly winds in respect of moisture, with the result that great stretches of country east of them are arid wastes. . . . In the rain shadow of the Sierra Nevada the mean annual rainfall is between 5 and 6 inches and locally as low as 3 inches." [60] It is well known that torrential and eolian deposition is most active under conditions of diminished rainfall, where as a result vegetation is scant. With a high Appalachia, then, to intercept the moisture-bearing west winds, we should have abundant vegetation and little deposition on the western slopes, but arid conditions and terrestrial deposits on the eastern. Thus it is evident that conditions like the present would not be conducive to the formation of such deposits as the Bald Eagle and Juniata. If, however, the winds were reversed; if, in other words, conditions were such as to permit winds like the trades to flow from the east across the high ranges of Appalachia, leaving the moisture which they brought from the Atlantic on the *eastern* slopes, and causing relative aridity on the western, the conditions found in the Bald Eagle and Juniata might readily be accounted for. They might indeed be postulated from the given premises. Such conditions now exist on the western slopes of the Andes in South America, which form a barrier for the southern trade winds. West of them the Atacama Desert of Chili extends from the mountains to the coast, as one of the most barren and forbidding wastes imaginable. If, by way of argument, we postulate the existence of such winds in late Ordovicic time in this part of the continent, we could understand that a moderate elevation of the Appalachian old land would induce heavy torrential deposits on the western slopes of this land-mass, such as are found in the fragment now constituting the Bald Eagle conglomerate. That this is only a fragment, the westernmost end of a once much more extensive fan, will presently be shown to be the case. Other fans of this type may have formed to the south, along the western slope of Appalachia and northward in the New England regions. But these have either been entirely removed by erosion or by metamorphisms have been rendered unrecognizable.

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[59] Isaiah Bowman: Forest physiography, p. 117.

If after the formation of the Bald Eagle fan or fans a further local rise of the Appalachian old mountain land occurred, the aridity of the interior or western slope would be increased, and torrential deposits would be replaced largely by eolian deposits, the thorough oxidation of which would eventually result in the formation of a red series. These oxidized deposits may extend to the margin of the sea and into it, for the presence of the sea might have no pronounced influence on the climatic conditions over the adjoining slopes of the Appalachian old land, such climatic conditions being determined by wholly distinct causes. That such periodic elevation of the old land might have taken place can not be denied. Indeed, the probability of repeated elevations is suggested by the fact that a pronounced deformation, with intense folding and faulting, brought the Ordovicic period to an end. Such successive risings might be considered preliminary movements, which culminated in the great Taconic Mountain revolution.

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[60] Ibid., p. 120.

The conditions most favorable for the formation of these late Ordovicic continental deposits are shown in the following diagram (figure 5), but it must be borne in mind that this is only one possible explanation, and that it apparently involves the recognition of a wholly different position for the earth's axis from the existing one. There may be other explanations, but I can not help thinking that in view of the succession of such deposits which, as will be shown in this and subsequent papers, are repeated four times in the Appalachian region, none can be so satisfying or can so completely account for all the phenomena observed. The full significance of such an arrangement and the possibility of its having occurred will be discussed in a subsequent paper.*

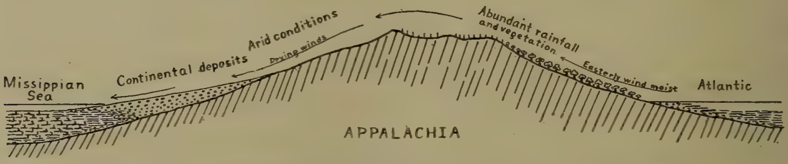

FIGURE 5.—*Hypothetical Sections across Paleozoic Appalachia*

Showing the deposits which would result if the prevailing winds were easterlies

PROBABLE EXTENT OF FOLDING OF THE STRATA AND SUBSEQUENT EROSION

General discussion.—As is well known, Ordovicic sedimentation was followed by a folding of the strata in the eastern part of North America. That this folding of the Ordovicic strata was in pre-Shawangunk time is indicated by the striking unconformity everywhere found between this rock and the Hudson series on which it rests. That it occurred long before the deposition of the Shawangunk, the age of which is basal Salina (basal mid-Siluric), is shown by the very pronounced character of the unconformity, and by the extensive erosion which the lower beds suffered before the deposition of the higher beds. That Richmond strata (chiefly the Juniata red shales and sands representing Richmond beds in the east) were involved in this folding is suggested by the succeeding events. This narrows the period of deformative movement down to the interval between early or middle Richmond and some time before the beginning of Salina time. The Susquehanna section indicates that this period must be narrowed still further, and that the folding took place during the otherwise almost unrepresented interval between Ordovicic and Siluric time. That this period was one of almost if not quite complete withdrawal of the sea from the interior of the North American continent is indicated by the widespread disconformity between Richmond and Clinton formations. This disconformity is marked in the Upper Mississippi region by pronounced indications of erosion of the older beds, especially the Maquoketa shales, which are classed by Schuchert as Middle Richmond. As has been shown by Weller[61] and others, these Maquoketa beds mark a widespread transgression of the sea during later Richmond time, resting generally with a disconformity on Trenton (Galena, etcetera). There is therefore much reason for believing that the entire Upper Richmond was deposited over the northwestern part of the United States. That this Richmond transgression was coincident with the spread of the Juniata fan is not improbable and is not at all inconsistent with the character of these deposits. The absence of highest Richmond in the Upper Mississippi section is to be accounted for by subsequent erosion during the emergence which preceded the Lower Siluric (Niagaran) transgression of the sea. That this interval was coëval with the folding and subsequent partial erosion of the Ordovicic strata seems probable and is indeed suggested by the character of the early Siluric deposits. An interesting fact, throwing some light on the character of the interior at this time, is found in the eroded surface of the Maquoketa shales of the eastern Wisconsin region and its relation to the succeeding deposits. The erosion plane is covered by shale pebbles which have a pronounced glossy surface, intimately suggestive of desert varnish. These pebbles form a pavement on which the early Siluric strata rest. These latter begin in at least one case with an oölitic iron ore, the form and structure of which is such as to suggest dunes of oölite similar to those now forming on the border of the Great Salt Lake. Subsequent replacement converted these oölites into iron ore[62] (figures

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* For a discussion of the "Pendulations-theorie," and the general problem of the shifting of the earth's axis, see Principles of Stratigraphy, chapter xxiii.

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[61] Stuart Weller: Journal of Geology, vol. 15, pp. 519-525.

[62] See A. W. Grabau: Physical and faunal conditions, etcetera, in "Outlines of geological history," p. 76. For the discussion of the general problem of oolite formation, see Principles of Stratigraphy, chapters ix and xi.

6 and 7). A disconformable contact with the underlying formations is further indicated by the Clinton of Ohio, which contains well-rounded foreign pebbles in its basal portion. The fact that the Juniata and succeeding Siluric deposits of central Pennsylvania are essentially concordant in dip, though separated by a disconformity and hiatus, shows that the effect of the post-Ordivicic folding was not felt as far west as this region. The absence of Juniata and Bald Eagle beds in eastern Pennsylvania, where they must have existed, since the material of which they are composed could only have been derived from the old land still farther to the east, is explained by the fact that the Taconic folding carried the bottoms of the synclines above the present erosion plane. When it is remembered that these folds were truncated, and that the region was essentially peneplaned in early Mesozoic time, and that, finally, Tertiary erosion has affected primarily this eastern belt, it is not surprising that all vestiges of the former eastward extent of these formations have been removed.

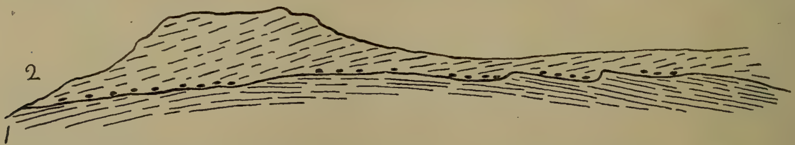

FIGURE 6.—*Section of the Oolitic Iron Ores of the Lower Siluric (2) resting disconformably on Maquoketa Shales. Iron Ridge, Wisconsin*

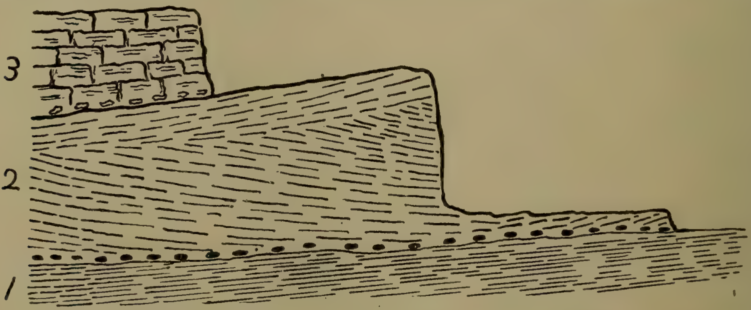

FIGURE 7.—*Cross-section of the Iron Deposit at Iron Ridge, Wisconsin*

1. Maquoketa shale, marked at the top by a layer of polished pebbles; 2, cross-bedded oolitic iron ore; 3, Maysville limestone

If we consider that the first effect of folding in this region was to throw the red Juniata beds into relief, and with these the underlying white Bald Eagle quartzites, we are compelled to recognize that the first fruit of subsequent erosion would be an abundance of red (or highly oxydized) material, followed by white quartzitic material, when the axes of the anticlines had been cut down to the Bald Eagle quartzites and conglomerates. Here I think we have the source of the Medina red sands and of the succeeding Tuscarora white quartzites, the Oneida conglomerate and its westward extension, the Thorold quartzite or upper gray band of Rochester, Niagara, and the northwestern region. These relationships are shown in figures 8 and 9. That a part of the beds classed collectively as the Juniata of Pennsylvania include some of the reworked Juniata of Medina age can not be questioned. It is this uppermost part which contains the Medina Scolithus (*S. verticalis*) and in some cases the Arthrophycus. Whether the sea advanced into Pennsylvania during this redeposition of the old Juniata sands and muds derived from the folded region of the east is not certain. Its existence in western New York during part of the time is proved. In any case, whether continental or partly marine, the contact of the Juniata and Medina would be obscured or rendered wholly unrecognizable, even though a consid-

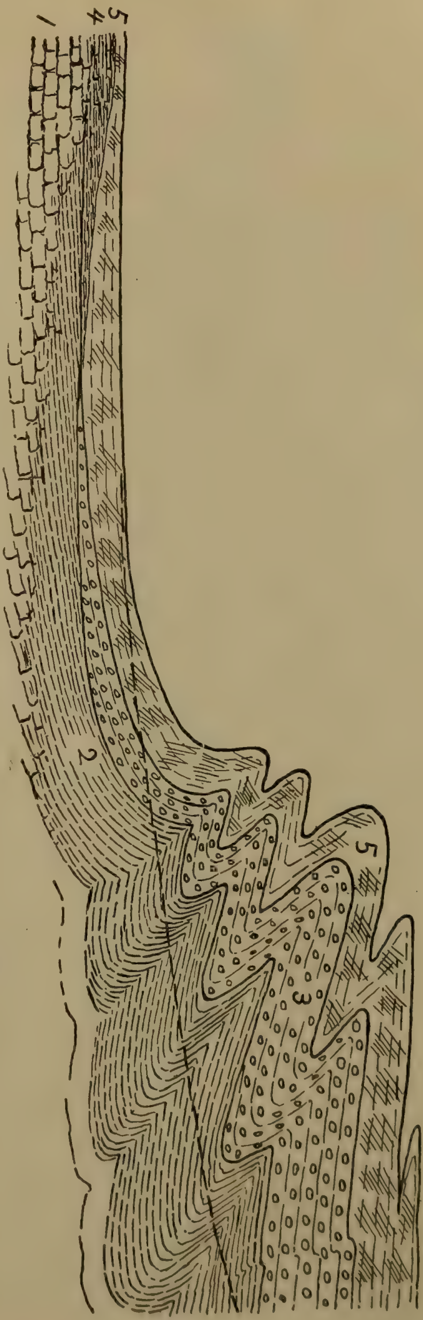

FIGURE 8.—*Diagram of the folded Ordovicic Strata at the beginning of Siluric Time*

1. Trentonian limestones; 2, Martinsburg (Utica) marine shales; 3, Bald Eagle conglomerate; 4, Richmondian; 5, overlapping Juniata

erable hiatus existed between the two. At the Susquehanna Gap at least 10 feet of this Medina series is shown underlying the Tuscarora. These beds will be more fully discussed in a later section.

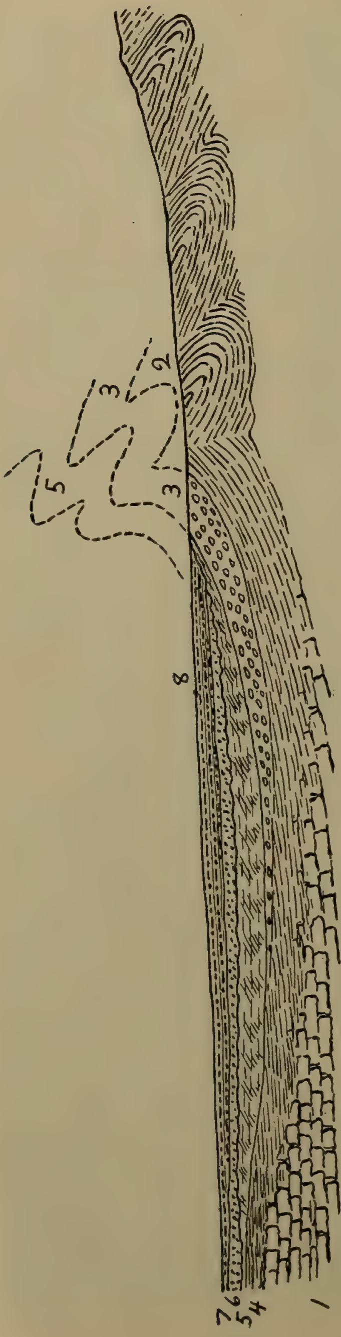

FIGURE 9.—*The same Section as Figure 8, but with the Folds eroded and the Material redeposited as Medina Sandstone (7) and Tuscarora-Oneida-Thorold Quartz Rocks*

The Bays sandstone—General results of studies made.—This sandstone, formerly also called Medina and generally correlated with that formation, appears at present to be restricted to the eastern counties of Tennessee and the adjoining area of southern Virginia and West Virginia and parts of eastern Kentucky. Fairly satisfactory descriptions of this formation are given in the folios of the Geological Atlas of the United States covering this section.[63] In the summer of 1906 I spent several weeks in the field studying this formation in Virginia, West Virginia, and Tennessee, and at that time I arrived at essentially the conclusions here given. Some of these have elsewhere been stated in print, but the entire problem has not been presented heretofore. It should be stated that my published conclusions have been severely attacked, but such attack has not found its way into print. Subsequently many of these conclusions have been generally adopted, especially those regarding the general Upper Ordovicic age of the formation. At the end of the present review I find myself standing essentially where I stood seven years ago with reference to the age, origin, and stratigraphic significance of this formation.

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[63] See especially numbers 12, 16, 25, 26, 27, 33, 44, and 118.

The greatest thickness recorded for this formation (1,500 feet) is north of Chilhowee Mountain, a mass of Cambric sandstone and conglomerate thrust over the Ordovicic strata. This is in Blount County, Tennessee, on the southeast corner of the Loudon quadrangle. The formation rests on the Sevier shale, which here is 2,000 feet or more thick and has several members of calcareous sandstone and some limestones. In character the Bays is here a somewhat calcareous red sandstone, with more or less feldspathic material and some white sandstone members. It is succeeded by the Clinch sandstone, which for the most part had been eroded in pre-Chattanooga time. Northwestward in this quadrangle the formation disappears by erosion, though here and there patches remain. These are generally rather calcareous. The Clinch is also absent in this region and the Rockwood, largely composed of the waste of the Clinton and Bays, rests on the erosion remnants or on lower formations down to the Chickamauga limestone.

It is a remarkable fact that nowhere west or south of this locality, in Tennessee, Georgia, or Alabama, is there any remnant of the Bays or the Clinch recorded. Throughout this section the Rockwood, composed largely of the debris of these formations, rests on the eroded surface of the Chickamauga limestone, or its shale equivalent, the Athens. Since the Rockwood is essentially Niagaran, except where it includes Medina and Clinch, a great amount of erosion is indicated for post-Bays-pre-Rockwood time, for not only have the southward and westward extension of the Clinch and Bays been removed, but also the whole of the Sevier shale, which in the Chilhowee Mountain region has a maximum thickness of 2,300 feet. From this we must conclude either that the Rockwood is of late Niagaran time or that it includes the true Medina at its base formed from the erosion of the eastward extension of the Bays, but not of the Clinch.* This will be more fully discussed in a later section.

In the southern extension of Bays Mountain, 8 or 10 miles southeast of Knoxville, Tennessee, the formation rests on the Sevier shale, which is here 1,200 feet or more in thickness. The Bays itself is not fully preserved, only from 300 to 500 feet occurring, this constituting the highest formation of the region. It is probably only the lower calcareous member of the series which is here seen. Southeastward, however, in the Chilhowee Mountain region, it reaches a thickness of 1,100 feet, and it here is a good red sandstone, and contains considerable feldspar, being at times an arkose. It is succeeded by the Clinch sandstone, of which, however, only a single slight mass, 6 feet in thickness, remains. The Clinch, or in its absence the Bays, is disconformably succeeded by the Chattanooga shale, there being no Rockwood preserved here. Northeastward, along the strike of the strata in the Morristown and Grenville quadrangles (numbers 27 and 118) near the Virginia line, we come to the type section in Bays Mountain, in Hawkins and Green counties, Tennessee. Here the formation is only from 300 to 500 feet thick and consists of a red calcareous and argillaceous sandstone, resting with apparent conformity upon the Sevier shale, which is here 1,500 to 2,500 or 3,000 feet thick, and contains beds of calcareous sandstone in the upper part, which forms a gradation into the Bays sandstone. It is interesting to note that reddish sandstones, the Tellico, occur low down in the Sevier, showing apparently the general existence at the beginning of Upper Ordovicic time of the conditions which became so marked toward its close. Throughout its outcrop in the section the Clinch sandstone succeeds the Bays with a thickness of several hundred feet, while the Rockwood here is essentially a shale. In the southwest end of the Bays Mountains the Bays sandstone is reported as more or less interbedded with the white Clinch sandstones near the top, though usually the formations are sharply separated. From these strata Keith says Silurian brachiopods have been obtained, but from his statement it is not clear whether these are in the transition beds and true Siluric species or in the basal beds and "Lower Silurian" or Ordovicic species. Ulrich, in his correlation table, makes the typical Bays sandstone of Upper Black River and Lower Trenton age, but gives no reason for such correlation. While it is not impossible that an earlier red series occurred in the Tennessee region (witness the Tellico sandstone and the Red Moccasin limestone), the fact that the Bays of the type section rests on a great development of Sevier shale, with which it forms a continuous depositional series, and that the Bays elsewhere in this region is of Lorraine and later age indicates that, so far as this sandstone is concerned, it is all of Upper Cincinnatian age. Northward and westward the Bays sandstone becomes more calcareous and thinner. While having a general thickness of 500 feet in Clinch Mountain, its thickness northwest of this section is seldom more than half that amount. Here as elsewhere the Sevier grades upward into the Bays, beds of reddish sandstone appearing in the upper part of the Sevier, followed by fossiliferous shales and limestones.

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* Ulrich has since shown that the typical Rockwood of southeastern Tennessee includes "representatives of the Juniata and of all the distinguishable members of the Upper Medina in New York, but that it does not include beds of Clinton age." (Bull. Geol. Soc. Am., vol. 24, p. 108.)

In the Powell Valley, at the base of Cumberland Mountain in northern Tennessee, occurs the westernmost outcrops of the Bays. It has here become a thin-bedded, red, argillaceous limestone and shale from 160 to 200 feet thick, but the top is worn away, the next succeeding formation being the Rockwood shales. The Bays rests here on red and green shales, marking the upper part of the Sevier formation. Little is seen of this formation, which seems to have been cut out by faulting or crushing. Nevertheless, the contact with the Bays is shown, or rather there is a gradation from gray to red shales, in which fossils of the Upper Cincinnati group abound. Near Jacksboro, Tennessee, I have succeeded in making the following section, which is only approximate on account of the great development of shear zones and faults. Much of the soft shales is probably crushed out owing to the pressure against the hard Carbonic conglomerates, which are here sharply upturned. The Bays is everywhere succeeded by the Rockwood, which here is chiefly a clay shale, with Clinton (?) fossils and bands of limestone and iron ore.

Section of the Bays-Sevier near Jacksboro, Tennessee.—Along the road leading up Cumberland Mountain and in the adjoining ravines (Briceville quadrangle), beginning at the base of the section, the Chickamauga limestone is exposed a short distance below the house of Mr. Sharp, the last inhabited house on the road. The dip of the strata here is 6° to the northwest, the strike throughout being around north 50° east. The limestone is very fossiliferous, carrying *Plectambonites sericeus,* Asaphus, etcetera. After a short concealed interval a soft, greenish gray clay shale is exposed by the roadside, having the same dip. Then follows an interval of about 650 feet in horizontal distance, over which no exposures are found. The next exposure begins with greenish and grayish to reddish shale, with included arenytes dipping 60° to the north. This is the beginning of the hill slope; between it and the limestone outcrop a valley intervenes, caused by the presence of the shale. It is probably in this interval that much of the Sevier shale has been crushed out.

There is, however, another aspect of the matter which must not be overlooked, namely, that the widespread absence of the Sevier shale from this point westward is due to the fact that it was never deposited as a shale. I do not believe that there was any break in deposition here between the Chickamauga and the Bays any more than that there was such a break between the Chickamauga-Sevier and the Sevier-Bays farther east. It looks more as if the Chickamauga limestone of this section 2,000 feet or more in thickness represented in its upper part what farther east is represented by Lower Sevier. Thus, in the section north of Bays Mountain (Knoxville quadrangle), the Chickamauga and Sevier are each about 1,000 feet thick and are separated by the Tellico sandstone from 250 to 500 feet in thickness. Still farther to the southeast, in the same quadrangle, the Chickamauga is only 50 feet thick, but it is followed by 1,000 to 1,200 feet of calcareous shales, the Athens, on which rest the Tellico calcareous sandstones and shales, 800 to 900 feet thick. Above this follows the Sevier shale, which here has increased to 2,200 or even 3,000 feet (4,000 feet is the estimated thickness at the northern end of Bays Mountain), and carries several heavy sandstone members. If we then assume that no elimination of beds by faulting has occurred, and rule out further hypothetical disconformities, we obtain about 300 feet, more or less, of soft shales as the representative of the Upper Sevier in this region, much of this being taken up by the concealed interval.

The lower 130 feet of the shales appearing next above the concealed interval are fossiliferous, containing *Plectorthis fissicosta, Rafinesquina alternata, Platystrophia* cf. *biforata, Zygospira* of modesta group, *Cleidophorous* cf. *planulatum, Calymmene senaria,* etcetera. This fauna is essentially an Upper Lorraine or about the middle of the Maysville.

The shales already show a reddish color, but this is not very pronounced, nor is lime a very prominent constituent of this section. For 15 feet above the last fossiliferous layer the strata become more sandy and somewhat more reddish. Then the cliff is covered for a distance of 125 feet, which with a dip of 60° would make about 105 feet of strata. Throughout this distance, however, variegated clays crop out at the base of the cliff. When the beds are exposed again, they are deep, brick-red clays, with occasional sandstones. No fossils have been found in these beds, which have a thickness of 40 feet. Then the section is again covered for a distance of 225 feet to the forking of the road. This corresponds to a thickness of about 190 feet, though variations in the dip make this only approximate. The section is continued in a stream channel below the road, where appear the same brick-red shales, alternating with pale-red beds. Occasionally bands of hard, greenish and red limestone occur in these higher beds. They stand out in relief among the clays, but no fossils have been found in them. In these limestones mud-crack structures have been observed. Overlying the limestones is a series of soft beds which are concealed for a distance of 250 feet, making a thickness of 200 feet, more or less. Over most of this area, however, the rock is just below the surface, which is full of fragments of a fine-grained, thin-bedded sandstone derived apparently from the concealed beds. Then follows the fossiliferous iron ore of the Rockwood, which, with its immediately inclosing beds, gives a thickness of 20 feet. After this follow thin, greenish shales and some sandstones, which have a total thickness of about 300 feet. The highest bed of the series is a soft fire-clay, which is succeeded by the Chattanooga black shale. Summarizing this section, we have the following:

	Feet	Feet
13. Chattanooga black shale.		
12. (Great hiatus and disconformity.)		
11. Greenish shales and sandstones with a terminal bed of fire clay, Rockwood formation	300	
10. Rockwood fossiliferous iron ore and associated rocks	20	
9. Thin-bedded sandstone mostly concealed, probably Rockwood.	200	
Total Rockwood		520
8. Red clays with included thin greenish or red limestone bands, the latter showing mud cracks, mostly covered	200	
7. Deep brick-red clays with occasional sandstones; no fossils	40	
6. Variegated clays mostly covered	105	
5. Sandy reddish clays and shales	15	
Total Bays		360 ±
4. Reddish, greenish, and grayish shales with numerous upper Ordovicic fossils representing late Lorraine age	130	
3. Covered interval, soft shales, thickness estimated	300	
2. Thin clay shales, partly covered, estimated	10	
Total Sevier shales		440
1. Chickamauga limestone.		

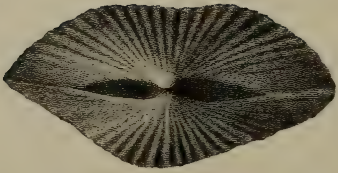
There is here a perfect gradation from the Sevier, with its Upper Lorraine fossils into the unfossiliferous Bays. This latter is mainly a clay shale, though calcareous beds are not wanting. There is no way of estimating the original thickness of this formation, nor is it known if the Clinch sandstone ever extended so far to the northwest. One would think it likely that this was the case, but proof for this is wanting.

The Bays Mountain anticline sinks out of sight after entering Sullivan County, Tennessee, a few miles below the Virginia State line, but a second pronounced monocline occurs to the north of it, running from Tennessee into Virginia. This is Clinch Mountain, the top of which is formed by the Clinch sandstone. The Bays sandstone just underlies it, but seems to be somewhat thinner in this mountain than it is farther north, due no doubt to unequal erosion. In the section along the road leading across this mountain above Mendota, Virginia (Bristol quadrangle), the contact between the Bays and the underlying Sevier is well shown on the north of the monocline. Here I found the following section exposed in the summer of 1906. The beds dip at a very uniform angle of 27° to 30° to the southeast and were well exposed for measurement and observation:

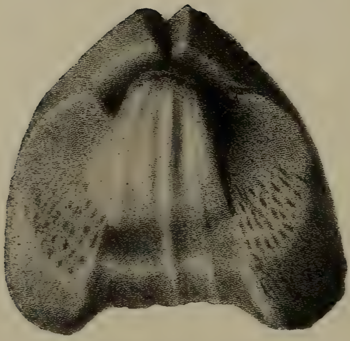
Section on Clinch Mountain near Mendota, Virginia

	Feet
9. Clinch sandstone.	
8. Bays sandstone, more or less well exposed; red, often cross-bedded....	295
7. Interval	10
6. Red sandstone and shale, typical Bays..............................	214
5. Red sandstone containing pelecypods, poorly preserved, but resembling *Amnigenia*..	40
4. Red fossiliferous sandstone and shale, grading downward into the underlying bed by a gradual change in color..................... The fossils obtained are: *Hormotoma* cf. *bellicincta*, crushed molds; *Tetranota* cf. *obsoleta* U. and S., internal molds.	8
3. Greenish, yellowish, and pinkish sandstones with *Byssonichia* cf. *radiata*, mostly crushed but common; *B.* cf. *præcursa* Ulrich, rare; *B.* cf. *obesa* Ulrich; Modiomorpha ? and other pelecypods, 3½ feet above the base occurs a 4-inch calcareous bed full of fossils, including: *Byssonychia* cf. *radiata; B.* cf. *richmondensis* Ulrich; *B.* cf. *obesa* Ulrich, and other pelecypods. Above this occur the following species up to 30 feet from the base: *Hebertella sinuata*, *Zygospira modesta*, *Zygospira* larger species, *Pterinea demissa*, *Byssonychia* cf. *walkerensis* sp. nov. Red beds appear commonly far down in this division, establishing a perfect gradation to the bed overlying.......	35
2. Calcareous beds alternating with shales, exposed at the turn in the road. Fossils mainly brachiopods, including: *Zygospira modesta*, *Zygospira* sp., and others, including a number of pelecypods........	4
1. Shale, gradually becoming more sandy upwards; the beds of sandstone increase in thickness and frequency until the formation is mostly a sandstone, some of which is of a reddish color, while most of it is greenish or gray. Fossils abound. This is typical Sevier shale. Thickness not measured. The total thickness of the Sevier shale for this section is given as about 1,300 feet by Campbell (Bristol folio).	

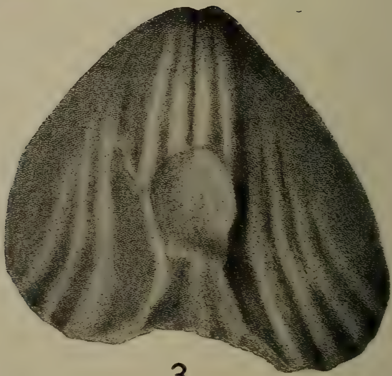
There is no question here of the intimate relation existing between the Sevier and Bays. The former grades upward into the latter. At first marine conditions still prevailed, while the deposition of "red" sands and muds had already begun, and the last of the survivors of the Cincinnati fauna of this region were embedded in the basal sandstones of the growing Bays delta. The total absence of fossils in the overlying beds and the general character of the formation clearly indicate that here was forming a subaërial deposit of highly oxidized sands and dust, similar to that which formed the Juniata farther to the north. The fossils indicate the age of the basal beds of the Bays to be late Upper Ordovicic, the precise correlation being perhaps Upper Maysvillian—that is, post-Lorraine. A decided Richmond element is also observable.



1



2



3

PLATYSTROPHIA PONDEROSA VAR. STEVENSONI GRABAU

1. Cardinal view of a cast (plastotype) from a rock mold.

2. Internal rock mold, showing the usual form of occurrence.

3. View of another specimen from the brachial valve side, showing natural median fold and plications.

All the specimens are natural size. Types in collection of Columbia University.

Clinch Mountain is replaced northeastward by East River Mountain, a pronounced monoclinal ridge, with strata dipping to the southeast and the eroded edges facing the Carbonic Plateau, from which it is separated by a narrow valley. Its crest forms the boundary line between Virginia and West Virginia in this section. The strata have been in part thrust up onto the younger beds, but on the whole little disturbance is noticeable within the beds of the mountain. Southward from this are a number of other ridges, among which is Big Walker Mountain, part of another overthrust block of these Ordovicic-Siluric strata, which here also dip to the southeast. This latter ridge may in general be considered the continuation of the Bays Mountain folds, bring up essentially the continuation of the strata of those mountains.

The Bays of Big Walker Mountain, Virginia.—A visit to Stevensons fossil locality on Big Walker Mountain enabled me to secure a goodly number of fossils from the soft, red Bays sandstones on the north side of the mountain, estimated at perhaps 100 feet below the Clinch. The general thickness of the Bays in this region is estimated by Campbell (Pocahontas folio) to be about 250 feet, which brings the fossiliferous horizon near the middle of the formation, though some greenish gray argillaceous beds are exposed in the road only a few feet below the fossil-bearing strata. These may be the top of the Sevier, which would make the thickness of the Bays formation much less and bring the fossiliferous horizon near the base. The beds are largely shale, but carry occasional heavy beds of sandstone, with a dip averaging 35° to the southeast. The fossiliferous bed is about 10 feet thick and fossils are abundant. Most of them are either external or internal molds.

PLATYSTROPHIA PONDEROSA VAR. *STEVENSONI* VAR. NOV.

Plate 12, Figures 1, 2, 3

The most abundant, and in some respects the most striking, species represented is a large, extremely rotund and short-hinged form of *Platystrophia lynx* (=ponderosa Foerste). The larger specimens measure 28 millimeters in height and 33 millimeters in width, with a hinge area 16 millimeters long. A typical specimen of *P. ponderosa* from Cincinnati measures 29 x 37 millimeters, with a hinge line 28 millimeters long. The Walker Mountain specimens are very rotund, the sinus appearing first as a gentle depression somewhat less abrupt than in the Cincinnati specimens. Anteriorly, however, it is quite as marked, and generally carries three plications, though occasionally a fourth appears. A striking feature of nearly all adult shells is the great thickness on either side of the rostral cavity and the strongly pustulose character of the shell in this region. This is seen in the old age specimens from Cincinnati, but appears to be the normal thing in this region. As a result, the internal molds always have a very strong projection in the beak area. The brachial valve has a thick but short median septum, to which are joined the converging crural plates. A small but distinct cardinal process occurs. The radial plications and concentric striæ are essentially as in the Cincinnati specimens. A local variety might be made of this, and the name *stevensoni* is proposed in recognition of the fact that our first knowledge of this region and of the fossils in this rock are due to Prof. John J. Stevenson, who worked out much of the structure and stratigraphy at a time when little was known of the Appalachians and accurate maps were not available.[64] Stevenson reported from this locality *Byssonychia radiata* and *Rhynchotrema capax*. The former is well represented, though the species is not *radiata* in the restricted sense. The specimens identified as *Rhynchonella capax* are more doubtful. Ulrich has identified them as *Orthorhynchula linneyi*, but a comparison with typical specimens of the latter from Kentucky shows that this identification is at least as faulty as the other. The specimens have the character of a young Platystrophia and either represent the young of *P. stevensoni* or a new species.

The following is a complete list of the species identified from the collections made in Walker Mountain:

BRACHIOPODA

Platystrophia lynx var. *stevensoni* var. nov., abundant and of varying sizes.

PELECYPODA

1. *Byssonychia walkerensis* sp. nov. The common species of Byssonychia in the Bays sandstone of Big Walker Mountain differs from *B. radiata*, to which it has generally been referred, in the greater height of the shell and the correspondingly shorter hinge line. Its most marked characteristic is the sharp anterior flattening or impression, the limiting angles of which are generally acute. The frontal portion thus outlined is very pronounced, broad and marked by stronger radii than those on the rest of the shell. The normal shell radii are flattened on the top and separated by narrower interspaces. There are about 36 of the radial plications. The height of a small specimen is 33 millimeters, the anteroposterior length 14 millimeters, the thickness 17.5 millimeters. Another

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[64] See his papers in the Proceedings of the American Philosophical Society, 1885; vol. 22, 1887.

specimen has a height of 44 millimeters, a length of 31 millimeters, and a thickness of 16 millimeters. This species is of the *B. richmondensis* type, but differs from that species in its proportions, as well as in the very sharp lateral angles. From *B. præcursa* Ulrich of the Upper Maysville of the Cincinnati region it differs in its proportion, the broader frontal portion, which is more flattened, and the sharper lateral angles.

This species is abundant in the Bays sandstone of Big Walker Mountain and has also been obtained from the Lower Bays on Clinch Mountain. A specimen apparently identical with the Bays sandstone species has been obtained from the Cincinnatian of Colby, Clarke County, Kentucky.

2. *B.* cf. *radiata* (Hall). Several fragments showing the more rounded front, more distinct plications, and greater width of the species, occur with the preceding.

3. *Orthodesma* cf. *canaliculatum* Ulrich. Several specimens showing form and strong muscular outline of this Upper Cincinnati shell.

4. *Modiolopsis* cf. *modiolaris*. Internal molds apparently of this species.

5. *Pterinea demissa* Conrad, rare.

6. *Ischyrodonta* cf. *decipiens* Ulrich. A specimen agreeing in form, outline, and markings with this Richmond species.

7. Cymatonota ? sp.?

8. Whiteavesia sp.?

Altogether this fauna has a distinctly Richmondian aspect, though it has also some late Maysville elements. It must be borne in mind, however, that precise correlation between rocks of distinct facies purely by fossil content is a hazardous undertaking. Different species occur with different facies, and the range of species in a sandstone facies may differ decidedly from the range of the same species in a limestone or shale facies. The most that can be said in the present case is that the fauna decidedly supports the view derived from other facts, namely, that the age of the Bays is late Maysville and Richmond.

The East River Mountain section.—This was examined by me in the Bluefield region. The first ledges met with in ascending the mountain on the Bethel cross-road from the north, above the typical Sevier shale, is a heavy bedded, coarse sandstone, the individual masses 4 to 5 feet thick, the color prevailingly white, though reddish in part. It is so coarse for the most part that it is better described as a fine quartz-pebble conglomerate. The pebbles are of white quartz, well rounded, varying in diameter up to a fourth of an inch, though averaging only about an eighth of an inch in diameter. Cross-bedding is well marked in this rock, with the inclination of the beds all directed the same way, which is toward the north. The rock seems to be especially coarse on the diagonal layers, the horizontal ones between them being somewhat finer. The thickest of the diagonal bedded layers measured 17 inches, which is not much above the average, though some of these beds are only 1 or 2 inches thick. Three ledges of this character appear in a space of 110 feet, dipping at an angle of nearly 45° southeast, though in one case this changes to 30° southeast. They are separated by covered intervals, probably underlain by shales. These sandstones have been referred to the Sevier, which is here about 1,300 feet thick. They apparently represent the extreme outer portion of a white quartzose fan of subaërial origin, similar in character and development, though probably not in extent, to the Bald Eagle delta fan of the region farther north.

Above these sandstones the outcrops are concealed until we come to within about 100 feet of the bottom of the Clinch sandstone, which forms the crest of the mountain. The lowest beds shown are heavy bedded red sandstones, with strong cross-bedding of the torrential type. Then follows a red shale, strikingly resembling the Queenston shale of the Niagara Gorge, and above this are more sandy beds partly red and partly mottled, containing small pebbles and vertical tubes filled with fine mud and probably referable to *Scolithus verticalis* of the Medina. Some of these beds are cross-bedded, as is the case in the lower sandy layers, the dip of this cross-bedding originally pointing northward. Among the float on this surface I found a specimen of *Arthrophycus harlani* in a piece of reddish sandstone apparently of this horizon, though it may have come from the Clinch, which has several iron-stained layers. Whether this is the case or not, it, nevertheless, seems quite likely that the upper diagonal bedded sands with Scolithus tubes are of Medina age, representing the reworked sands derived from the erosion of the southeastward extension of the Bays sandstone, when this was brought into the erosion zone by the Taconic elevation. This would put a pronounced hiatus between the red shales and the sandstones, the former being late Ordovicic, the latter early Siluric.

Whether these red beds come to an end farther to the northeast, or whether they are continuous with the Juniata of western Maryland, has, I believe, not been ascertained. In Highland County, Virginia, and in the counties immediately to the south and east (Staunton quadrangle) they seem to be represented by the lower part of the Massanutten sandstone. This formation, 500 feet or less in thickness, comprises an upper white or gray quartzite, which represents the Clinch of the south or the

Tuscarora of Pennsylvania, and a lower, softer, thinner-bedded, red or brown sandstone and quartzite which merges into the sandy beds of the Martinsburg below. How much of these red beds belongs to the Ordovicic and how much to the Siluric (Medina) has not been ascertained. The fact that the red series varies considerably in thickness might indicate that most of it is Siluric (Medina), while the fact that the beds grade down into the Martinsburg would indicate that the lower part is Ordovicic, with a hiatus between it and the upper portion. A few impressions of shells have been recorded from dark shaly beds about 200 feet above the Martinsburg, but no determination of species seems to have been made. We have thus apparently a continuous succession of Upper Ordovicic strata for a distance of 350 or 400 miles from southwest to northeast. From the fact that the formation disappears abruptly south of its thickest development, it would seem that it may have extended for at least 100 miles more to the southwest. The linear extent of the northwest and southeast outcrop is less than 90 miles, but, when the extensive folding and faulting is taken into consideration, it will be found that it was originally at least twice that. The easternmost outcrop of these beds is now removed about 50 miles from the old land which could have supplied the material. Doubling this on account of folding and thrusting—here probably occurring at least twice—and we get a total extent of at least 300 miles northwest and southeast for the former extent of these beds. The probabilities are that it was nearly 400 miles. Whether this represented one delta or several confluent ones can not now be determined. Considering the northeast-southwest extent, the probabilities are that these beds represent several confluent members.

The thickness of the present beds gives us no clue to the thickness of the beds at their maximum, even if it were possible to separate the Ordovicic from the Siluric part, for extensive erosion has affected this area as it affected the region of the Juniata fan. The eroded material here as there was redeposited as continental or seashore Medina sand, a deposit probably present in greater or less thickness in most of the sections of the southern Appalachians, especially the western ones. A part of the eroded material was also redeposited as the Rockwood sands, which is thickest and coarsest where the Bays has been entirely removed by early Siluric erosion.

The question may now be asked, Was there any deposit corresponding to the Bald Eagle farther north? If it is true, as I believe it is and hope to show presently, that the Tuscarora quartzite is derived from the erosion and redeposition of the eastern extension of the older Bald Eagle beds which had been folded and elevated at the end of Ordovicic time, it is probably true that the Clinch sandstone had a similar source, and that hence in the region from which these beds have now been removed by erosion there existed one or more fans of white quartzite beneath the red beds. The fact that the Upper Sevier shale in many places is a sandy bed, and the further fact that on East River Mountain beds of white conglomeratic quartzite underlie the Bays sandstone, lends a strong element of probability to this supposition. Of course, we have no means of knowing whether any large part of this pre-Bays or Upper Sevier sandstone deposit was of subaërial origin or whether it was merely a coarse shore deposit which furnished the sands for the Clinch formation. In any case the purity of that sandstone suggests that it is a secondary deposit derived from an older sandstone and not directly from the crystallines.

Summary of the Bays problem.—Summarizing the preceding discussion, we note that the sections indicate a continuous presence of red sandstones and shales in the Appalachian ridges for a distance of over 300 miles northeastward and southwestward. Its greatest thickness, 1,300 feet, is in the southernmost portion of the belt, south of which the formation, as well as the overlying and underlying one, is wholly wanting. The belt of red rocks extends now over an area of about 90 miles of folded rocks, which would give perhaps 200 miles of area when the folds are straightened out.* The formation probably extended originally to the crystallines on the southeast, by the erosion of which the material was derived. This adds at least 100 miles to the original northwest and southeast extent of this deposit and probably it was nearer 200 miles. The red formation, known throughout as the Bays sandstone (except in central western Virginia, where it is included in the Massanutten sandstone), is not a stratigraphic unit. Its lower part is probably everywhere of Upper Ordovicic age, passing into the underlying sandstones and shales with marine fossils. The lower part of the red beds in many places also contains fossils, these generally being of Upper Lorraine or post-Lorraine types. The red beds probably begin earlier in the southeastern region and later in the northwestern, having the arrangement of a northwesternward-replacing overlap. The highest part of the red series is of early Siluric (Medina) age in many of the sections, especially those in the westernmost belts. This is shown not only by the coarser character of the beds, but also by the few fossils found, especially *Scolithus verticalis* and *Arthrophycus harlani*. The interpretation which satisfies apparently all the characteristics of these deposits is that of a huge subaërial delta fan, or a series of smaller confluent fans, formed during a period of relative aridity and preceded by a period of more pluvial conditions, during which white or gray quartz sands and pebbles were spread out over part of the same territory occupied by the red beds, but of less areal extent. The red beds along their margin dipped into the sea and the deposits inclosed the remains of the marine organisms then living. The greater part of the delta was, however, subaërial in character, its head or heads being the old land of Appalachia, 100 or more miles southeast of the easternmost outcrop of today. After the deposition of an unknown thickness of such material, probably several thousand feet in the southeastern area, deposition was interrupted by the folding of the strata. This folding was the southward continuation of the folding affecting the red Juniata and underlying beds to the north, commonly known as the Taconic folding. This occurred toward the end of or after Richmond time, as before noted. After the folding erosion was renewed, attacking this time the red beds first and spreading the material, resulting from this erosion, over the more or less eroded surfaces of the westward continuation of these same red beds. This constituted the southern equivalent of the Medina formation. The uncovering of an underlying, unoxidized quartzite by erosion of the folded area furnished the material for the later-formed pure Clinch sandstone. The successive (1) red, (2) red, and (3) white beds of the northern and southern Appalachians had thus a similar history and are of the same age respectively.

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* R. D. Chamberlin's studies of the Appalachian folds leads him to conclude that the compression of the folds west of Harrisburg was from 81 to 66 miles.

The Medina and the Tuscarora and Clinch formations and their extensions in eastern United States.—The Medina beds of the Great Lakes region.—The Siluric of eastern North America begins with the Medina formation wherever that has not been removed by later erosion. In Wisconsin and Iowa the base of the series is calcareous and rests on an erosion surface of the Maquoketa (Richmond) shales. In northeastern Wisconsin a local deposit of iron ore separates the two formations, this iron ore consisting of flattened pellets of uniform size and most probably representing a replaced oölite. Irregular cross-bedding in the deposit, as well as the arrangement of the individual grains, the absence of fossils, and the local lenticular character of the deposit, all suggest an eolian origin, the ancient calcareous oöids probably forming in a neighboring saline lake or sea, being heaped up into dunes, to be subsequently covered by marine deposits and later replaced by iron, probably in the form of carbonate, which was then oxidized to the sesquioxide. As already noted, a layer of flat clay pebbles, covered by a highly polished coating of iron oxide, suggests aridity and warmth, with the production of a desert varnish. That all of these deposits were forming on dry land is shown not only by their character, but also by their contact with the underlying rock. The sketches (figures 6 and 7, page 444) taken from my notebooks show this contact near Iron Ridge, Wisconsin. The basal bed of the succeeding dolomite contains limestone pebbles and fragments of Stromatoporoids.

In northwestern Ontario the basal Siluric beds are marine limestones and dolomites resting, probably with a disconformity, on red Queenston shales. From their nearly continuous exposure along the lake front in the township of Keppel, from Owen Sound to Cape Commodore, the name *Keppel dolomites* will be applied to them. At Cape Commodore 109 feet of Queenston shales rest on the Hudson, and are followed by about 36 feet of thin-bedded Keppel dolomites. Then follow about 150 feet of red shales and some sandstones. These red beds are again well exposed at Cabots Head, the northeastern point of the great peninsula separating Lake Huron and Georgian Bay. Here they are 103 feet thick, and consist of red, marly sandstones, partially striped and spotted with green, and interstratified with beds of red and green argillaceous shale, none of them, however, exceeding 6 or 8 inches in thickness. This is the Tobacco-pipe rock of the Indians, and it is succeeded by 55 feet of green, calcareo-argillaceous shales and thin-bedded limestones, above which follows the Pentamerus limestone, considered the western extension of the Walcot of Niagara. The red and green beds will be named the *Cabots Head beds,* and they are believed to be the westward extension of the true Medina sedimentation, which at Niagara is about 125 feet thick.[65] The Keppel dolomite is an earlier marine deposit before the sands and muds from the Appalachians reached this point, or during the earlier period of the erosion of the folded red beds of the Ordovicic. Fragments of the Cabots Head beds contain *Helopora fragilis* and *Phænopora explanata* Hall, the former abundant in the Upper Medina of the Niagara section, and occurring also with the Phænopora in the Clinton ore bed at Flamboro Head. Eastward from near Collingwood and Nottawassaga the red Medina beds are separated from the overlying Clinton by the gray band, which from its exposure at Thorold, Ontario, on the Welland Canal, will be called the *Thorold quartzite.* This band is traceable eastward, occurring everywhere at the top of the Medina from this point to Rochester and Oswego. Beyond this point it is represented by the Oneida conglomerate, and both formations are to be regarded as the overlapping upper portions of the Tuscarora quartzite of Pennsylvania. In western New York and Canada the Thorold quartzite is seldom over 10 or 12 feet in thickness, but on the extreme northwestern point of its occurrence, in the township of Nottawassaga, Ontario, it is said to be 35 feet thick. This is about 350 miles in a direct line from the outcrops in central Pennsylvania. Where the Keppel dolomites are absent, as in the region southeast of Collingwood generally, the line of division between the Queenston and Medina beds becomes obscured. At Niagara and for some distance east and west it is marked by the Whirlpool quartzite, a hard, white quartz sandstone 25 feet thick, which rests abruptly on the red Queenston shales, as shown on the river above Lewiston or Queenston. This rock shows beach cusps and other characters which indicate that the seashore was near. A. W. G. Wilson has interpreted this lens of sandstone as the remnant of an old dune area reworked by the advancing sea,[66] and this interpretation is favored by the character of the grains composing this rock as well as by its distribution. Some of the bedding surfaces of this quartzite show wave-marks closely resembling those of modern shallow beaches, a feature repeated in a number of higher beds farther east. The Whirlpool quartzite is not known at Rochester, where the contact between the Queenston and the Medina is again obscured, a condition which practically exists throughout the rest of the area covered by these rocks. The Whirlpool quartzite is thus seen to be a local formation apparently unconnected with any direct eastern source. The section of the Medina along the Niagara Gorge is as follows,[67] the Clinton or Sodus shale being included:

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[65] The entire series has recently been named the Cataract formation by Schuchert. Preliminary announcement of papers Geol. Soc. Am., New Haven Meeting, Dec., 1912.

	Feet
Super-formation. Clinton lower limestone (Wolcott limestone).	
8. Sodus shale. Olive green to grayish, sometimes purplish gray shale, with occasional fossils especially *Anoplotheca hemispherica* and *A. plicatula* and impressions suggesting *Pterinea emacerata*. Reed-like impressions also occur....................................	6
(Abrupt contact.)	
7. Thorold quartzite. Hard, massively bedded, compact, quartzose sandstone, resembling the Whirlpool sandstone, and commonly showing irregular cross-bedding, and showing in one place a couple of beach cusps 15 feet apart with the central portion depressed nearly 2 feet below the crests. Sometimes a thin basal bed is separated by a few inches of reddish shale from the main mass. Further west in Ontario this rock carries *Arthrophycus harlani*..........	7½

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[66] A. W. G. Wilson: Transact. Canadian Institute, vol. 7, pp. 139-186.

[67] A. W. Grabau: Bull. 45, N. Y. State Museum, pp. 89-95.

Feet

(Contact generally abrupt; sometimes a few inches of shale intervene.)

6. Medina red sandstones. Massive sandstone in beds from one to several feet in thickness and varying in color from reddish to grayish. Irregular cross-bedding generally well shown, together with local cut and fill phenomena, the wedging out of beds, etcetera. A few fossils are found in the lower, more regular beds, especially *Lingula cuneata*, while *Arthrophycus harlani* is restricted in this section to the under side of this division, projecting downward into underlying shales.................................... 12 to 15

5. Medina variegated sandstones and shales. Compact, solid, reddish or gray sandstone, mottled with red, in beds from 4 to 6 inches thick, separated by shaly partings with occasional beds of red shale 2 to 4 feet thick. About 20 feet above the base of this series is a concretionary layer from one to two feet thick, which appears not unlike a bed of large rounded bowlders. These concretions vary in diameter up to 3 or 4 feet, and they lie in close juxtaposition, not infrequently piled one upon another. Thinning out of layers in all directions is a common phenomenon, and ripple marks are frequently met with on the sand beds, one of the layers 10 feet above the base showing ripples with their crests 1 to 1½ feet apart. Fossils are more common in these layers, the following having been obtained: *Lingula cuneata*, *Whitfieldella oblata*, *Modiolopsis orthonota*, *M. primigenia*, and fragments of others................ 35 to 40

4. Gray and greenish gray Medina shales, intercalated toward the top with reddish bands and finally changing to red altogether........ 6

3. Gray Medina sandstone. Porous and calcareous sandstone and sandy shales, some of the former massive and in beds 6 or 7 inches thick separated by shaly layers. Fragments of fossils are common and often appear to have been dissolved out. Many of the thinner beds have ridges on their under side, the filling of grooves or trails in mud below. Small black phosphate pebbles or nodules, often very smooth, are not uncommon in some of the layers, suggesting small worn fragments of fish bones. Larger pebbles of carbonaceous shales are also found occasionally. The fossils are mostly Gastropods and pelecypods, but some thin layers are covered with poorly preserved fragments of what seems to be the Bryozoan *Helopora fragilis*. Other fossils found here are: *Camarotœchia* sp., *Uncinulus stricklandi*, *Plectorthis medinaënsis*, *Rhipidomella* sp., *Pentamerus* sp., *Modiolopsis orthonota*, *M. primigenia*, *Pterinea* cf. *emacerata*, *Pleurotomaria parvetusta*, *P. littorea*, *Orthoceras* sp., *Ascidaspis* sp., *Dalmanites* sp., etcetera.......................... 5

2. Gray Medina shales. Fissile clay shales, gray in color and generally free from sand, but with occasional sandy intercalations, and even thin-bedded white quartzose sandstones near the center. Fossils are scarce, *Lingula cuneata* being the most common. From being coated by red mud these shales generally appear red in the cliff... 25

1. Whirlpool quartzite.. 25

Total Medina.. 120 to 130

Eastward at Lockport and Medina certain of the upper beds are quite fossiliferous, sometimes presenting almost the character of an organic rock. Such agglomerations consist of the shells of *Pleurotomaria parvetusta, Buccania triloba, Isochilina cylindrica,* and Pelecypods, especially the two "Modiolopsis" before mentioned. *Lingula cuneata* is also common, especially on slabs of higher sandstone, where single valves often show the arrangement adopted by modern bodies on a flat beach under the influence of the run-off of the waves. Wave-marks are also associated with these fossils, the ensemble being clearly one of beach phenomena. Still farther east, at Rochester, the series becomes almost unfossiliferous. The line of contact between the Medina and Queenston is here obscure and marked by the appearance of coarser sediments. Some of the upper beds are even pebbly and most of the series is sandy. Several heavy sandstone beds occur, and these usually show marked cross-bedding commonly of the eolian type, but some torrential bedding also occurs. These latter beds near the top also show ripple-marks. Fossils occur just below the Thorold quartzite and are chiefly *Arthrophycus harlani,* Dædalus, and other structures of this type. Sarle[68] has interpreted these as the work of burrowing worms, an interpretation which may hold for the Dædalus, but scarcely for the Arthrophycus. The latter always projects downward from the under side of sandstone into the mud layers beneath, and thus represents the natural mold of a series of grooves, with characters the reverse of those shown in the specimens preserved, while generally filled in by sand. Cases have been reported from Oswego County near Fulton where small pebbles are mixed with the sand.[69] Such arrangement could only indicate grooves filled by material spread over the surface in which they were formed. Such grooves are difficult to explain except as a series of tracks. These tracks would have a pronounced median ridge and a series of sharp transverse ridges on either side of this, separated by concavities. There is no organism known in these rocks capable of making such a track. A split caudal fin, used regularly for propulsion, might perhaps account for this, as shown by Woodworth,[70] for the very similar, but larger trails, known as Climatichnites, from the Potsdam sandstone of northeastern New York. If such a creature was an inhabitant of the sea, it is exceedingly strange that no remains have been found of it. If it was a land animal frequenting the shores or the sand flats adjoining, we can more readily understand its absence from these rocks, though we would at least suppose that an occasional individual would become embedded in the strata. Among Eurypterids only the Pterygotus-like Erettopterus has a bilobed telson. A small species of this genus moving on the sandy river bottoms or the beach might perhaps have produced such a structure, if it used its telson for regular propulsion. Again, the organism may be referable to myriopodus types or to Insecta. Whatever the type which caused these trails, there can be no question of its wide distribution, for it is found along the whole Appalachian front. Nor can its preference for the higher shore zone, if not for river bottoms, be doubted, since these markings are never found in immediate association with marine fossils and are commonly preserved by a cevering of sand, which shows cross-bedding of the eolian type and which probably represents accumulations of blown sand.

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[68] Rochester Acad. Sci., 1906, vol. iv, p. 203.
[69] Vanuxem: Report of Third District, p. 73.
[70] New York State Museum Report, Bull. 69, 1903, p. 959.

Mud cracks are common features in the red shales of the Medina east of Rochester, and indeed the beds here have much more the aspect of having accumulated for the most part above water. They appear to represent the dry land continuation of the beds forming the shore and littoral deposits west of Rochester. The Thorold sandstone terminates the Medina series, but has a thickness of only 5 feet in this section. A peculiar structure, described by Conrad as *Dictyolites beckii,* covers a large portion of the Thorold quartzite in this section. This has the aspect of being some form of fimbriated mud crack, though it may have a wholly different significance not yet ascertained. The Medina sandstone has not been recognized east of Oneida County, New York, its last representation being in Cherry Valley. The underlying Queenston does not extend so far, being unknown in the northern section east of Rome, New York. The Thorold quartzite, however, extends farther east, becoming the Oneida conglomerate, which in the vicinity of Utica rests on the eroded surface of the Frankfort shale.

The red Medina beds are well exposed at Fulton on the Oswego River, where they are capped by hard, red sandstones carrying *Arthrophycus harlani.* The succeeding Oneida conglomerate is here buried by the drift. Eölian cross-bedding is common in these rocks, and the total thickness of the series here is less than 100 feet. The contact with the Queenston is not exposed and probably would not be recognizable. The base of the section is formed by the Oswego sandstone, which causes a second fall within the city of that name.

In Oneida County the Oneida conglomerate alone occurs. South of Utica this is about 40 feet thick and a pure quartz pebble rock, with quartz sand as a matrix. The pebbles are well worn and indicate a secondary origin—that is, derivation from an older conglomerate—not only by this fact, but also on account of the purity of the rock as a whole. It is well cross-bedded, the bedding being of the torrential, rarely the irregular type, and it rests on an eroded surface of the Frankfort shale, with indications of old erosion channels. On the south branch of Moyer Creek, 3 miles southwest of Frankfort, Herkimer County, the basal conglomerate likewise rests on eroded Frankfort shale. The entire series here is something over 100 feet thick (Hartnagel estimates it at 110 feet),[71] and the upper beds show remarkably fine diagonal bedding (torrential cross-bedding), the oblique layers being very long and followed by heavy horizontal beds. It is interesting to note that not only the coarseness, but also the thickness of these terminal Lower Siluric (Niagaran) clastics increases eastward. East of Herkimer County, however, the Oneida is generally absent, and the same is true of the region north of the Mohawk, Upper Siluric (Monroan) strata resting directly on the Ordovicics in the northern Helderbergs.

The Tuscarora.—Southward along the Appalachian front we do not meet with these strata again until we come to the Susquehanna Gap through Blue Mountain. Here the contact with the Hudson beds is not shown, but from the general relationship of the dip there may well be an unconformity here. The following section (figure 10), transcribed from my note-book, shows the relation of the strata. The Hudson beds of argillaceous sandstones and shales dip gently to the west, while the Siluric beds are overturned to

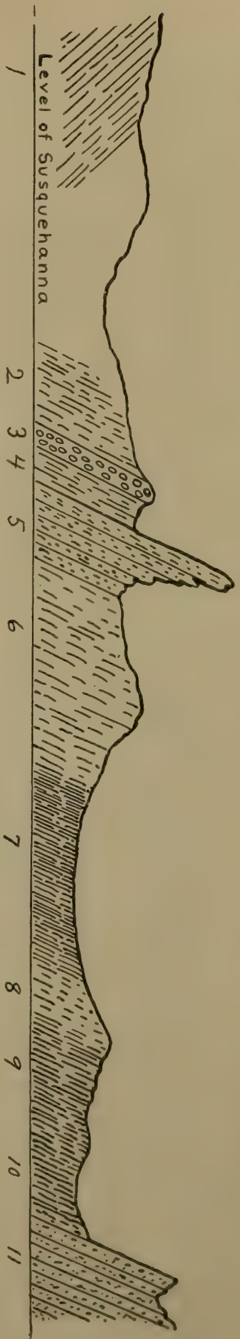

FIGURE 10.—*Section along the right Bank of the Susquehanna above Harrisburg*

1, "Hudson" shales; 2, Medina red sandstone; 3, conglomerate, 5 feet; 4, red shales; 5, conglomerate (Tuscarora); 6, Tuscarora quartzite; 7, Clinton beds; 8, 9, Bloomsburg (Longwood) beds, with sandy beds (8) representing the Shawangunk; 10, reworked Bloomsburg; 11, Hamilton sandstones.

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[71] Bull. 107, N. Y. State Museum, p. 29, pls. I and II.

about 75 or 70°, thus making the contact, if the dip does not change, a rectangular one. After the covered interval about 10 feet of red sandstones appear, somewhat conglomeratic. Then follows a coarse conglomerate or pudding stone, 5 feet thick and composed of a great variety of pebbles. Again a shale bed occurs and then a conglomerate, with red shale pebbles. Above this comes a thickness of about 120 feet of white quartzite, some of the beds being marked by *Arthrophycus harlani* and others by trails, mud flows, and so forth. Pebbles are not uncommon in some of the beds and clay galls abound in others, while toward the top occur again some red beds. Conglomerate beds are found at frequent intervals. The whole is succeeded by the Clinton, which here also contains much red material, and this is followed by the Salina red shales. These conditions can be traced northeastward to Swatara Gap.

Throughout Pennsylvania the Tuscarora has in general the same distribution as the underlying red beds. These red beds, as repeatedly noted, are not throughout of the same age, but in many sections a hiatus and disconformity occur some distance below the top, the beds above this hiatus being of Siluric or Medina age and those below of Ordovicic or Queenston age. The disconformity is not recognizable in the sections, but careful search might reveal the evidence for it. The deposition of the reworked material, derived from the eastern extension of the older beds directly on the western part of these same beds, would give very little indication of a break, especially as the top beds of the older series were probably reworked to some extent before the later beds were deposited. Furthermore, the existence of such a hiatus would be obscured by the presence of numerous smaller breaks in the series, such as are characteristic of river-laid deposits. It may be that the new series begins in most cases with coarser beds, since the material is derived from the coarser eastward extensions. But even this criterion may fail in some cases. Of course, if characteristic Siluric fossils were present in the upper beds, the Siluric age of the beds could then be proven, just as late Ordovicic fossils in the lower beds prove their Ordovicic age. Here the *Arthrophycus harlani* may be used, since so far as known this does not occur below the Siluric. The *Scolithus verticalis* is also serviceable to some extent, though of much less importance.

The thickness of the Medina portion of the Juniata is consequently not known, but I doubt if it is much over 100 feet in most of the section, and in some it is probably much less, though an occasional greater mass may easily be found. On the whole these deposits are restricted to the more westerly outcrops, the Tuscarora resting more often on the Juniata in the east.

The Tuscarora in most of the sections is characterized by *Arthrophycus harlani.* In Pennsylvania its lower part may contain very coarse quartz and other pebbles, forming in rare cases an "egg conglomerate." Cross-bedding is commonly of the torrential type, though excellent examples of eolian bedding are also seen. The thickness varies greatly, but on the whole it is thicker in the central part of the State and thins out in all directions north, west, and south. Thus along Bald Eagle Mountain it has a thickness of 1,068 feet at Tyrone Gap, though of this fully one-half may belong to the Medina. It decreases to 400 feet in Wills Mountain at Milligans Gap and to 287 feet at the Maryland line. Here it is continuous, with the red Medina underlying, which also shows good torrential cross-bedding. It is a snow white to light gray quartzite, frequently cross-bedded, the quartz grains being of medium size. Yellowish green, hard clay pebbles occur in it and *Arthrophycus harlani* is largely restricted to the upper beds. In the lower beds, in the center of the Wells Creek section, I have observed eolian cross-bedding and the grains are fine, uniform, and well rounded, suggesting an eolian origin. Northward along Bald Eagle Mountain the thickness is also variable. Thus at Bellefonte Gap, in Center County, it is 400 or 500 feet thick; in Mill Hall Gap, 695 feet. In the Lycoming County gaps it is only 100 feet. Farther eastward the thickness also varies. Thus in Logans Gap through Jacks Mountain it is 820 feet and is composed of hard, massive layers from 2 to 4 feet in thickness. Some argillaceous material occurs, but the sand is exceedingly pure. Secondary enlargement of grains has made them angular and sharp where they separate out. Twenty-five miles west of this point, at the Juniata Gap of Jacks Narrows, the Tuscarora is 450 feet thick, and 10 miles farther south, at Orbisonia, it is 400 feet and contains some red layers. In the northeastern counties of Pennsylvania and Maryland its thickness varies between 200 and 300 feet, rarely becoming more. In the Mercersburg-Chambersburg quadrangle, Stose records an average of 270 feet, which in the Maryland and Virginia regions (Pawpaw-Hancock folio) is similar or decreases to 200 feet. A remarkable feature of the sandstone in the southern region is its whiteness and purity, though occasional shale bands occur. These should contain Eurypterid fragments. *Arthrophycus harlani* is the only fossil so far found.

The Clinch sandstone.—The Clinch sandstone is in all respects the equivalent of the Tuscarora of Pennsylvania. It rests on the red beds (Bays), which, like their northern representatives, the Juniata, generally represent a double formation, an older of late Ordovicic age, the equivalent of the Queenston, and a younger of Siluric age, the equivalent of the New York Upper Medina. The hiatus between the two is just as much obscured as in the northern sections, and there is not much hope of even finding the line of contact between the two. How much of the red is Siluric and how much Ordovicic can probably never be ascertained, but that both are represented is shown by the Upper Ordovicic fossils in the basal part and the early Siluric fossils in the upper. The latter, however, are the least satisfactory.

The distribution of the Clinch is in general coextensive with that of the Bays, though the latter occurs where the former has been largely or wholly removed by subsequent erosion, which, however, occurred in Siluric time. In thickness the formation ranges from nothing to 500 feet, the maximum occurring near the center of the area, though disappearing more abruptly southward. The present thickness is no criterion by which to gage the original thickness, which was probably much greater. A great part in the southern area seems to have been used up in the making of the Rockwood sandstones. These latter were deposited along the border of a transgressing sea, so that the beds come to lie on eroded members of various older formations.

The northward and westward extension of the Clinch beds dips under the younger strata of the Allegheny plateau and does not reappear again. In the Nashville and Cincinnati domes these beds seem to be unrepresented, but it must be remembered that extensive erosion occurred in these regions during middle and perhaps later Siluric time.

SUMMARY OF THE EARLY SILURIC DEPOSITS

If we now attempt to summarize these early Siluric deposits and trace the history of their formations, we are met at the outset by the fact that the order of deposition is the reverse from that which we found in the late Ordovicic. There we had white conglomerates and sandstones deposited first, followed by highly oxidized sands and muds which now are dehydrated and red. Here we have coarser red sediments first, followed by pure white sandstones or conglomerates. Siluric fossils, especially *Arthrophycus harlani*, seem to characterize both red and white beds.

A further fact to be considered is that these beds as well as the underlying ones are wholly absent between the Appalachian ridges and the crystalline old land, from which they must originally have been derived. Furthermore, while the beds of the two series are as a rule concordant, being separated only by an hiatus and disconformity, there is indication at the Susquehanna Gap—though not proof—that the Tuscarora and

Medina are both unconformable to the underlying Hudson beds. Since we know that the older strata in the east were folded at the end of Ordovicic time, we seem to have here indication that this folding was also in pre-Medina time.

If we conceive of a series of strong folds formed along the eastern area of the Appalachian region at the end of Ordovicic time, the surface rock of such folds would be the red Juniata-Bays, while beneath would be the white or gray Bald Eagle, also involved in the folds, but at first out of sight. Erosion, which would set in at once, would thus attack the "red"[72] rocks first and so furnish oxidized sands and muds which are spread by the rivers over the surfaces west of the folds, an area which had not been included in the folding. Thus red sands and muds of Siluric age derived from the folded, red Ordovicic rocks would come to rest on the undisturbed western ends of the red Ordovicic rocks. If the sea encroached here, these later deposits would have a marine aspect, but the fact that fossils are absent in most cases, except for the peculiar *Arthrophycus harlani* and the "worm" tubes, would indicate that these beds were deposited above the sea, along river floodplains. Westward, however, the northern series of deposits (the Upper Juniata) were washed into the sea, the shore of which during Medina time did not probably extend much farther east than Rochester. In western Ontario encroachment of the sea began earlier, for here we have the marine Keppel dolomite resting on a surface of Queenston. These dolomites were probably formed while erosion was beginning in the east and while the early Medina sands were spread by the streams over the old Ordovicic land surface. Then as the product of this erosion was carried farther westward by repeated reworking, it finally entered the sea, which had then advanced farther east. Thus the fossiliferous Medina beds of western New York and the red and green Cabots Head sands which rest on the Keppel dolomite were deposited.

As the axes of the anticlines in the east were worn away, the underlying Bald Eagle conglomerate was discovered and white quartz sands and pebbles were now furnished to the streams. It should probably be considered that the lithification of these beds had not progressed very far, and that hence the streams did not find it too difficult to obtain the material. The reworking by streams and winds of these older white quartzites produced the material of the Clinch and Tuscarora. Where streams were active, coarse material was carried along and deposited as quartz pebble conglomerate which, because of its origin from an older conglomerate and the thorough assorting of the material, became very pure. Such is the Oneida conglomerate of Herkimer and Oneida counties, New York, which rest disconformably on the eroded surface of the Frankfort. The western extension of the white beds on the red Medina are seen in the Thorold quartzite of Rochester, Niagara, and the west, which has been traced to Collingwood, on Georgian Bay, a distance of 300 miles from the deposits in Pennsylvania.

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[72] It should be remembered that under this term oxidized rocks are meant. They need not have been red at the time of the folding.

With the beginning of Medina transgression ensued again a period of prolonged marine conditions, the sea extending farther and farther, to be followed by a period of extensive retreat and laying bare of the continent in Salina time.

THE NIAGARAN MARINE INTERVAL

The transgression of the Niagaran Sea across the North American continent appears to have been of a rather complex type. It seems certain that there were at least two opposite movements, one from the north, the other from the south. It appears that while Medina-Tuscarora sediments were still spread by the rivers from the Appalachian highlands, the sea encroached from the region of the present Arctic Ocean and entered the country by way of the upper Great Lake region. The Keppel dolomites seem to have been the earliest deposits here, though farther north still earlier ones may appear. From the south a transgressing sea entered the Mississippi Valley, with the result that the Alexandrian formation was deposited there. This formation contains a commingled Ordovicic fauna, such as characterized the transition beds in the Atlantic Ocean, as shown by the Anticosti section. When a junction was effected between the northern and southern encroaching seas, a certain commingling of the faunas took place. On the whole, however, the faunas remained more or less distinct, as shown by a comparison of fossils from the Wisconsin and Kentucky-Tennessee region. Ulrich misinterprets this difference of faunas as due to variation in horizon. This leaves out of consideration the common facts of modern faunal distribution.* The hiatus which Ulrich places between the Rochester and Lockport, in order to make room for some southern formations, is absolutely non-existent. I have for years studied these formations in the Niagara Gorge, and I am absolutely convinced that no such hiatus exists. The Rochester shale by becoming more calcareous passes without a break upward into the Lockport dolomite. To be sure, there is a peculiar type of deformation in the basal beds of the Lockport or the top of the Rochester, a creeping and interstitial rearrangement of the fine calcilutytes, with accompanying deformation which looks like a complicated series of foldings. This is a structure long familiar to German geologists under the name "Gekröse," for which I have substituted the term *enterolithic* structure.[73] It is a phenomenon accompanying the diagenetic alteration of certain fine calcareous rocks and is in no case of tectonic origin. A similar structure is seen in the otherwise horizontally bedded salt deposits of the New York Salina and in numerous deposits in various parts of the world. Its occurrence might easily lead one not familiar with such things to think of a tectonic deformation of the beds, and in some cases in the Niagara Gorge it suggests superficially an unconformity and hiatus. Such does not, however, exist, and the differences in faunal character found in the Niagaran beds of the different parts of the country must be accounted for by the variation of the factors influencing the distribution of organisms. Nor does such difference of faunal character in closely adjoining districts necessarily imply actual land barriers, for we have abundant evidence today of different faunas in closely adjoining districts of the same ocean. One might cite the fauna of Casco Bay and of Massachusetts Bay and again compare the latter with the faunas of Vineyard Sound. This disregard of other than continental barriers deprives Schuchert's work in paleogeography of much of its value, for his successive paleogeographic maps are chiefly based on the principle of land barriers for faunal separation.

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* For a summary of these, see Principles of Stratigraphy, chapters xxvi to xxix.

It is highly improbable that during deposition of the marine Niagaran any direct connection existed with the Atlantic in the Appalachian region. Not only was the Appalachian old land the source of the clastic sediments, but the materials here are coarse and in many cases merge into continental sediments. Indeed in most cases along the Appalachians the Niagaran beds (Rockwood) are largely the eroded and reworked continental clastics of early Silúric and late Ordovicic time which preceded them. Schuchert's maps, which show connections with the Atlantic in the New York City region during Clinton and Rochester time, are most certainly at fault. These maps may be further criticized in that they show Niagaran formation distributed over too limited an area. They leave out of consideration the fact that an enormous amount of erosion has occurred during Salina time and also during Monroe time, the evidence for which will be given presently. It is difficult to understand how Schuchert has his extensive calcareous deposits accumulating in little shallow basins surrounded by land, each basin being in many cases not much larger than one of our present Great Lakes. He must conceive of North America as persisting in a chronic state of peneplanation, so that only fine terrigenous sediments or none at all could be supplied. Apparently little or no allowance is made for the subsequent removal of the formations by erosion.

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[73] See F. Felix Hahn: Neues Jahrbuch für Mineralogie, etc. Beilage Band xxxvi, pp. 34-37, pl. iii, fig. 2; also text figure 15. See also Principles of Stratigraphy, chapter xx.

Personally I am of the opinion that a large part of the calcareous Niagaran strata extended over the interior and western portion of the North American continent, and that extensive erosion during Middle Siluric (Salinan) time has removed a large part and subsequent erosion a still larger part of these deposits. I believe that we will be forced to come back to sounder stratigraphic principles than those now followed by some American stratigraphers, and not regard every little deposit faunally distinct from others as a separate invasion of the continent by the sea.

THE MID-SILURIC DELTA FANS OF NORTH AMERICA

General discussion.—The Niagaran or Lower Siluric period of marine deposition came to an end with the deposition of the Guelph-Lockport dolomites of New York and Canada. Ulrich, to be sure, places the Louisville coral limestones above the Guelph, but as this is evidently merely a personal opinion of his, unsupported by evidence adduced, we may disregard it. The Louisville is certainly the reef facies of the later Niagaran deposits of the north, formed while the Lockport dolomites were accumulating in the New York area and westward. This is where it is placed in the much saner correlation table by Schuchert.

Marine deposition was brought to an end by the general withdrawal of the sea from the North American continent. This was probably largely an epeirogenic movement, a general elevation of the land, accompanied by local orogenic movements in the continent of Appalachia. Or we may consider the withdrawal of the sea, this negative eustatic movement, as due to deepening of the ocean basins, in which case we should expect to find evidence of such withdrawal in other continents as well. There is some indication to the effect that such withdrawal has taken place, followed by a readvance of the sea. In Bohemia Barrande's *Etage* F_1, corresponding paleontologically to our Upper Monroe, rests with a disconformity on *Etage* E_2. The latter appears to be Niagaran, though *Cardiola interrupta* suggests a somewhat later age.

That the sea did withdraw from North America is clearly shown in the sequence of the formation. Throughout the known areas of the continent, with the possible exception of the northeastern area in Nova Scotia and adjoining districts, the top of the Niagaran, where not followed by the Salina deposits, shows evidence of erosion prior to the deposition of the Upper Siluric or later formations over it. The Salina deposits extend from the Helderberg and Kittatinny Mountains on the east to Michigan on the west. The southern boundary extends from Maryland northwestward into northeastern Ohio and thence into southern Michigan. The present northern boundary is approximately coextensive with the northern outcrops of the Siluric strata of New York, Ontario, and Michigan. The formation is thus seen to occupy an elongated basin, comprising most of New York and Pennsylvania and much of Ontario and Michigan, with extensions into Maryland on the east and Ohio and perhaps Indiana on the west. The deposits of this area consist of clastics on the east and an alternation of clastics and chemical precipitates in the form of rock-salt, gypsum, and anhydrite in the western area. The clastics on the east are clearly derived from the Appalachian old land still farther to the east, this being the only possible source of supply. These clastics comprise two types. The lowest is a conglomerate, usually made up of more or less well rounded quartz pebbles and quartz grains, except in its easternmost extension, where pebbles of other material also occur. This is the Shawangunk conglomerate, traceable along the northern Appalachian front from south of Kingston to some distance below the Schuylkill Gap in the Blue Mountain of Berks County, Pennsylvania, near the Lebanon County line. Its westward extent is unknown, as the formation dips beneath younger strata and is not brought up again, nor is it reached by wells. Its eastward extent has been traced to the Green Pond-Skunnymunk Mountain region in northern New Jersey and New York, where it is represented by the Green Pond conglomerate. The conglomerate is practically everywhere succeeded by a red shale and sandstone formation, which in the eastern section at Green Pond Mountain is known as the Longwood shale. In the Helderbergs of New York this formation, originally called Medina, has been renamed by Hartnagel the High Falls shale from High Falls on the Rondout River. In Pennsylvania the red beds have in the past generally been referred to the Medina, though certain portions have been recognized as Salina under the name Bloomsburg shale. As will be more fully shown in the detailed description, both the conglomerates and the red beds are thickest in the east and thin out in all directions away from the source of supply. The series is an almost exact repetition of the Bald Eagle-Juniata series, deposition beginning with coarse pebble and sand beds and passing into red sedimentation. As in the case of the lower series of deposits, fossils are absent from these formations, except in special cases to be mentioned hereafter, and, like the lower series, this, too, must be considered of continental origin, as will presently be shown. But whether or not we accept the continental origin of these deposits, it is evident that a land-mass large enough to supply several thousand feet of clastic strata must be of sufficient extent to be an effective barrier between the Salina basin and the Atlantic. Certainly no connection with the sea could exist in the region fronted by these deposits, and if a connection did exist it must have been either to the north or to the south.

The extreme northeastern outcrop of the Shawangunk conglomerate is a little north of Binnewater station, on the Walkill Valley branch of the West Shore Railroad between Kingston and Rosendale. Here it is about 10 feet thick and for the most part still carries good-sized pebbles. The High Falls shales which overlie it also overlap it northeastward and extend to within a few miles of Kingston. From south of Kingston to the head of the Helderbergs at Altamont, successively higher strata of Upper Siluric (post-Salina) age rest on the eroded Hudson beds. These strata are marine and they mark a transgression of the sea in that direction. It is evident that this region was land before the deposition of the Cobleskill, Rondout, and Manlius beds, and that hence no connection with the sea could exist in this direction. No one has considered a connection with the Atlantic north of this across the Adirondack region, for the impossibility of maintaining such a hypothesis is apparent; we realize that nowhere in this region are there any remnants of Siluric strata of any age until we reach eastern New England. These, as is well known, belong to an Atlantic district, distinct from that in which the typical Siluric strata of North America accumulated. Moreover, it is pretty certain that the material of which the water-lime and the Manlius limestone of eastern New York were formed was derived from the erosion of the Ordovicic limestones (Trenton and earlier) which then covered the Adirondacks; and since there is further every reason for believing that the Lorraine beds also covered the Adirondacks, at least to a large extent, it is evident that these must have been removed by erosion prior to the attack on the limestones. There is, then, sufficient evidence to warrant the conclusion that an extensive region from Kingston northward and eastward was above water and subject to erosion, and that hence no connection with the Atlantic was possible in this direction.

What has been said of northern New York applies equally well to Canada. Nowhere in Canada north of the Salina basin are any post-

Niagaran strata known, although the Niagaran beds have a wide distribution. To imagine a connection across this region with a distant Arctic Sea would require the subsequent complete removal of the deposits thus formed. That is, of course, not impossible, but to say the least is highly improbable. Such a supposition would also require the removal of all deposits formed in this Arctic Salina Sea, unless, what is not impossible, some of the beds classed as Niagaran in the north prove to be of later age. There is, then, in this direction a possibility of a connection with an Arctic Sea, but, as will be shown later, the characters of the deposits within the Salina basin are such as to practically forbid such an assumption.

If we now examine the deposits of northern and western Michigan, eastern Wisconsin, Illinois, Indiana, northwestern Ohio, and southeastern Michigan, we find that practically everywhere the Upper Siluric or Monroe strata rest on the Niagaran. This means that these regions were land during Salina time and so freed from receiving deposits. The widespread erosion of the Upper Niagaran and the frequent absence of late Niagaran beds may be attributed to such erosion before the Upper Siluric Sea covered this region again. From Ohio to the Appalachians the formations are out of sight beneath younger deposits, but when they reappear in the disturbed eastern region similar relationships exist. Thus at Cumberland, Maryland, the Salina is wholly wanting, the Lower Monroe beds of Upper Siluric or post-Salina age resting with a disconformity and hiatus on the Niagaran, the highest beds represented being, according to Prouty,[74] of Rochester age. These Lower Monroe beds of the Cumberland region have generally been referred to the Salina, but I have convinced myself by personal observation that such a reference is erroneous. They form one continuous stratigraphic series, with the beds recognized by their fossils as Upper Monroe, and their thickness does not differ materially from that of the Lower Monroe of Michigan which overlies the Salina. What few fossils have so far been obtained from these limestones indicate a late Siluric age and bear out this correlation.

Between the limestone of Upper Monroe age and the highly fossiliferous Niagaran limestones lie 11 feet of sandstone, often ripple-marked, and 30 feet of thin-bedded calcilutytes, mostly nodular, and alternating with shaly layers. The sandstones probably represent the Keefer sandstones of the section farther east. They comprise, in descending order, a 3-foot bed of ripple-marked sandstones, iron stained and somewhat disintegrated in parts; a 2-foot bed of calcareous sandstone and a 6-foot bed of light yellow sandstone. The underlying nodular limestones and shales are referable to the Niagaran, as shown by their fossils. Overlying the sandstones is a 4-foot bed of thoroughly disintegrated rock, stained brown by iron hydrate and including rounded boulders of limestone, some of them from 1 to 3 feet in diameter. The boulders are not residual, for they are perfectly solid, only showing a certain amount of oxidation from the surface down. They have the aspect of old limestone boulders worn round during exposure to the air, probably by streams, and embedded in a deposit of calcareous mud, rich in iron, which has since become disintegrated. This argues a period of exposure in post-Niagaran time, as indeed is also shown by the absence of the higher Niagaran strata. The intervening sandstone is, as shown elsewhere, referable to the Shawangunk. Similar conditions exist farther east, but here the series is complicated by the red sediments, as will be more fully discussed below.

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[74] Wm. F. Prouty: The Meso-Silurian deposits of Maryland. Amer. Jour. Sci., vol. xxvi, 1908, pp. 563-574.

Considering all the sections, it seems impossible that any connection could exist between the Salina basin and the Atlantic. It certainly could not exist across Maryland, as sometimes suggested; for, as we have just seen, the eroded Niagaran surface is here succeeded by Lower Monroan, with only an 11-foot, unfossiliferous sandstone series intervening, while, moreover, indications of the existence of a long land surface are found between the sandstone and the lower Monroan.

Schuchert in his recent paleogeographic map of Salina time places the connection in the northern New Jersey and southern New York area. It is difficult to understand how such a supposition can be brought into harmony with the sediments in this region; for it is just here that the clastic sediments are at their thickest and their coarsest, and it is equally plain that a large land-mass must have existed here and to the east which supplied the materials of these clastic formations. This is not only shown by the fact that the coarseness and thickness of the series are here at the maximum, but also by the fact that there is absolutely no other source than the great land-mass here which could supply such a volume of sediment. This will appear fully as we discuss the sections in detail. This postulate of a great land-mass as the source of the material in this section is imperative, whether we consider the deposits in question marine or continental.

We may now proceed to a detailed discussion of the sections and their significance. In all cases the question of continental *versus* marine origin of the deposits will be kept in mind during the discussion.

Details of the sections—In general.—In presenting the details of the section, I wish to limit myself to the more salient features, especially in the case of the conglomerates, since this formation has been studied in great detail by Mr. Paul Billingsley, a graduate student in Columbia University, whose work is to be published elsewhere.[75] Careful perusal of his studies and the conclusions drawn therefrom is recommended.

The Green Pond conglomerate and Longwood shale of the Paleozoic fault-block of New Jersey and eastern New York.—A long outlier of Paleozoic strata, the eastern extension of the beds found in the Front Range of the northern Appalachians, occurs in northern New Jersey and southeastern New York. The ridge forms Green Pond Mountain at the south and Skunnemunk Mountain on the north. Intense folding and faulting have complicated the original synclinal structure and rendered measurement of sections difficult. The mass is separated on the west by a fault throughout its entire extent, and there can be no question but that it was originally connected with the strata of similar age in the Front Ridge of the northern Appalachians farther west. In this outlier the eastern extension of the clastic mid-Siluric beds are found in the Green Pond conglomerate and the Longwood shale.

The name "Green Pond conglomerate" was originally applied to two distinct formations, but was restricted by Darton in 1894 to the basal Siluric conglomerate, exposed in the vicinity of Green Pond Mountain, New Jersey, and representing the age equivalent of the New York Shawangunk.[76] Its thickness was estimated by Krümmel and Weller[77] to be approximately 1,200 and possibly 1,500 feet in the center of the area, from which point it decreases northward and southward. At Skunnemunk Mountain, New York, Hartnagel measured 250 feet, but some portion of the formation is concealed. At the railroad section near Cornwall station only about 25 feet are shown. Southward it likewise thins away, though measurements are not available.

The rock consists throughout of coarse, red conglomerates in its lower part and buff and reddish quartzites in the upper, these characters remaining uniform throughout. The pebbles are largely quartz, from one-half to 3 inches in diameter, with a dull red sandy matrix. Pebbles are usually numerous, but decrease in number locally. They are generally well rounded, but may also be angular. In one place large masses of the underlying limestone are included. At Cornwall, where the conglomerate rests unconformably on the Hudson series, the pebbles range in size up to 2 inches. As compared with its next western exposure, the conglomerate has thinned considerably in Green Pond Mountain. The Shawangunk conglomerate, its equivalent at the Delaware Water Gap, is, according to the careful measurements of Mr. Billingsley, about 1,900 feet thick, the distance between the two points being less than 24 miles. If the conglomerate were a marine formation, this thinning toward the source of supply would suggest progressive overlap against the old land. If, on the other hand, the conglomerate is of terrestrial origin, this thinning may be regarded as due either to subsequent erosion of the upper beds before the deposition of the succeeding formation or to a backward overlap of the strata of a growing delta, in which deposition with decreasing gradient will successively extend farther up the stream in the direction of the source of supply.

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[75] Manuscript deposited in Columbia University.

[76] Bull. Geol. Soc. Am., vol. 5, 1894, p. 383.

[77] Geol. New Jersey, Ann. Report, 1901, p. 13.

The name "Longwood shales" was also introduced by Darton for the red beds everywhere succeeding the Green Pond conglomerate, and has been generally adopted for these beds, though local names are used in New York (High Falls) and Pennsylvania (Bloomsburg). At the type section in Longwood Valley east of Middleton, New Jersey, the formation is estimated to have a thickness exceeding 200 feet. In the northern end of the fault-block the Longwood shale has decreased to 119 feet in thickness, the beds being well exposed in the railroad at Cornwall. The beds are coarser below, apparently grading down into the Green Pond conglomerate and become finer upward. The shale is mostly of a bright red color, but some thin layers of lighter colored shales are found interbedded. The beds are terminated in the northern part of the section at Cornwall station by a 1-foot bed of shaly, brecciated limestone, followed by sandstone and light colored quartzites carrying the Upper Siluric (Decker Ferry) fauna.

The Longwood shales here as elsewhere show characteristics pointing to a subaërial origin. This is seen not alone in their color, but also in the presence of mud cracks and of clay galls in the more sandy layers.

Although the greatest thickness of the beds in this ridge is only something over 200 feet, their thickness across the valley, in the Kittatinny Mountain region, is over 2,300 feet. Whether the great reduction on the east is largely due to original difference in deposition or mostly to subsequent erosion can not now be determined. Certainly there was extensive erosion of these red beds in early Upper Siluric time; for the beds succeeding the Longwood in the Green Pond-Skunnemunk outlier are of Upper Monroe age, beginning with the Decker Ferry formation, which includes at the top the Cobleskill and is succeeded regularly by the Rondout and Manlius. The thicker series of Longwood beds across the

Kittatinny Valley, however, is succeeded by upper members of the Lower Monroe group, the Poxino Island shale and Bossardville limestone. Between the latter and the more recent Decker Ferry beds is sometimes found a quartz sandstone composed largely of well rounded quartz grains, suggesting eolian origin. This quartzite, the Croasdale quartzite, apparently represents the Sylvania horizon of Michigan and suggests a break of some magnitude between the Lower and Upper Monroe.[78] Apparently throughout the whole of Lower Monroan time the red shales of the present outlier were subject to erosion, the eroded material furnishing the Lower Monroe sediments farther west and south. When finally this area was covered by the sea in Upper Monroe time, the upper layers of the remaining red series may have been in part incorporated as reworked material in the base of the Decker Ferry series. The occurrence of crinoidal fragments and of a few pelcypods[79] in the higher red strata at Cornwall suggests such a reworking in Upper Monroe time.

Ulrich and Schuchert in their paper on "Paleozoic seas and barriers in eastern North America," [80] page 654, give the impression that they advocate the accumulation of the deposits in the Green Pond-Skunnemunk area in a basin or trough distinct from those in which the corresponding deposits across the Kittatinny Valley accumulated. Their statements are rather vague and this may not be what they intended to say. Still they speak of the "Skunnemunk trough," which is apparently a syncline and holds a series of formations aggregating in the southern section 5,400 feet.

That the Siluric strata of this section accumulated separately from those of the more western area can not for a moment be maintained, especially when the basal clastics are considered. It ought not to be necessary at this stage of stratigraphic science to have to argue for the former continuity of extensive series of clastics which at the present time are discontinuous, but parallel, as in the present case, especially when it must be apparent that the only source from which the material of the clastics of both areas is derived is a land-mass which lay east of the easternmost of the two. Certainly no fact in the purely physical stratigraphy of this region stands out more boldly than that the separation of the formations on opposite sides of the Kittatinny Valley is due to erosion. It is for this reason that such misleading terms as "Skunnemunk trough" should be discarded.

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[78] A detailed study of the formations as exposed in the Broadhead Creek section of Pennsylvania will soon be published by Miss E. Kurtz, a graduate student in Columbia University.

[79] Recorded by Hartnagel.

[80] Bull. N. Y. State Museum, No. 52, 1901, pp. 633-663.

The Shawangunk formation of the Front Ridge of the northern Appalachians.—Considering now more fully the distribution and character of the typical Shawangunk conglomerate, we begin with the fact that its greatest known thickness is in the Kittatinny Mountains in the region of the Delaware Water Gap, where, as already noted, it aggregates 1,900 feet. The formation rest unconformably on the Hudson beds, beginning with a coarse pebble conglomerate, in which, besides the prevalent quartz pebbles, pebbles of compact mud rock are also found. This same general relationship to the Hudson beds is maintained in all the sections northward to near Kingston, New York, and southward for some distance beyond the Schuylkill River. Northward the thickness decreases, according to the measurements of Billingsley, to 1,500 feet at Culvers Gap, New Jersey, 800 feet at Otisville, New York, and to 500 feet at Minnewaska, New York. At High Falls the thickness, according to the borings made by the Metropolitan Water Board, is 345 feet, while at Rosendale scarcely 100 feet persist. Finally, at Binnewater station, there remain only 10 feet of conglomerate, and near Kingston it has disappeared altogether. The distance from its thickest point at the Delaware Water Gap to the point where it disappears north of Binnewater is almost exactly 100 miles, giving an average decline of 19 feet per mile. Southwestward the decrease in the thickness is to 1,500 feet at the Wind Gap, 1,125 feet at the Lehigh Water Gap, and 590 feet at the Schuylkill Water Gap. The distance to this point is only about 55 miles, giving an average decrease of 24 feet per mile. That the formation has not entirely disappeared after it ceases to be a prominent feature in the landscape is shown by the occurrence of a sandstone of the same age, and apparently constituting its southward extension on the Maryland border, nearly 175 miles southwest from the Delaware Water Gap. This will be referred to again later on. No trace of the rock is known in the northwestern outcrops of the Paleozoic strata, and it is not unlikely that its actual extent under cover is not much north or west of Elmira, New York. The Ithaca deep well did not reach the bottom of the Salina formation, and the one at Seneca Falls, Seneca County, New York, which passes through this formation, shows no recognizable representative of the Shawangunk, the red Vernon shales, with some mottled red and green shale, totaling 250 feet, lying directly on the Niagaran limestone series.[81] In general character the Shawangunk is a white quartz pebble conglomerate, but with many intercalated layers of sandstone and shale. The change from the one to the other is generally abrupt. Very often the sandy layers show the complex type of cross-bedding found in eolian rocks, while the conglomerate beds show the compound oblique bedding characteristic of torrential formations. This latter type of cross-bedding Mr. Billingsley found to predominate, being the characteristic type of the formation from bottom to top and from one end of its outcrop to the other. The direction of the oblique layers when corrected for later disturbance is generally to the northwest. The shales are generally sandy and dark colored to black; they are mostly limited to the lower half of the formation, and in several localities, notably at Otisville and the Delaware Water Gap, they have furnished an abundant but extremely fragmentary fauna, consisting chiefly of Eurypterids. The species so far described are *Eurypterus maria* Clarke, *Eusarcus cicerops* Clarke, *Stylonurus myops* Clarke, *Stylonurus cestrotus* Clarke, *Stylonurus* sp. *Dolichopterus otisius* Clarke, *D. stylonuroides* Cl. and R., *Hughmilleria shawangunk* Clarke, *Pterygotus globiceps* Cl. and R., besides fragments referred to Phyllocarida. These remains and their bearing on the general problem of the origin of the formation will be discussed farther on.

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[81] C. S. Prosser: American Geologist, vol. vi, 1890, p. 203.

The petrographic character studied at length by Billingsley shows several interesting features. The pebbles of the formation seem to be nearly all vein quartz, while in point of wear they are not so well rounded as are those of the Oneida conglomerate. Mingled with the sand grains of the matrix there is an abundance of feldspar, much of it in a very nearly unaltered state, so that the rock frequently assumes the characters of an arkose. This is, of course, not found where eolian cross-bedding is well developed, as in an outcrop on the Schuylkill River studied in detail by Billingsley. Here the remarkably fine development of the eolian cross-bedding was accompanied by great purity of the sand, a striking assortment of the grains according to size and a great perfection of rounding of the individual grains. On a lithological basis, Billingsley was able to divide the Shawangunk formation into two parts. The lower division comprises coarse conglomerates with intercalated black shales, often carrying Eurypterids and with gray sandstones, showing the presence of carbonaceous particles under the microscope. With this occurs bog iron ore, and the whole series has the aspect of having accumulated under comparatively moist climatic conditions. This portion of the formation disappears in the sections north of Otisville and south of the Lehigh. The second division consists at the base of coarse, white conglomerates and sandstone rich in feldspar and passing upward into red sandstones and shales. This division overlaps the lower one to the north and south, being the only one present in the Shawangunk Mountains and northward and on the Schuylkill Water Gap.

The Longwood shales and sandstones.—This formation holds its character and thickness for some distance along the Front Ridge of the northern Appalachians. At Culvers Gap, New Jersey, it is about 2,200 feet thick, and consists of red sandstones alternating with red shales. The sandstones are often cross-bedded and very commonly carry an abundance of red clay galls. Now and then a bed of greenish or grayish shale of slight thickness may occur, but the formation is prevailingly and strikingly of a red color. At the Delaware Water Gap, where the thickness is much the same, the character also has not changed much. The Shawangunk, which is here 1,900 feet thick, has some ferruginous layers, and it alone was referred to the Medina and the Oneida, while the red and green shales overlying were referred to number V of the Pennsylvania series and made to include both Clinton and Salina. As a matter of fact, no Clinton occurs here, as that belongs wholly below the Shawangunk, with which this section begins. The subdivisions given by the Pennsylvania Survey for these shales are as follows:

	Feet	Feet
Strata concealed by Cherry River Valley		740
Upper red shale	155	
Variegated shales and sandstones	450	
Lower red shales	740	
Lower olive shales	340	
		1,685
		2,425

The lower series is more sandy and is to be included with the Shawangunk. The lower red shales contain many sandstone bands, which by their cross-bedding, their clay galls, etcetera, indicate the mode of their formation. The clays also commonly contain mud cracks, though these are not always easy to observe on account of the ready shattering of the rock. Some of these mud cracks from the Schuylkill section of the Longwood, in rather greenish beds, penetrate to a depth of 3 or 4 inches or more, indicating a prolonged period of desiccation, during which the parched ground was baked hard and cracked deeply. On the Delaware the central part of the Longwood contains more greenish sands and shale layers than is found in the sections either north or south. At the Wind Gap nearly 2,400 feet of red shales and sandstones occur, while the Lehigh shows nearly 2,500 feet of these strata, according to the recent measurements of Mr. Billingsley. Chance's measurements give only 1,275 feet for the Lehigh Gap, but there is a concealed portion which Lesley thought is also occupied by the shale and of which he says "an estimate of 1,000 feet would probably be considerably below the mark. . . . It is more probable that 2,000 feet of concealed shale exists." [82] This would place the thickness of the Longwood series over 2,275 and under 3,275 feet, a thickness greater than that found anywhere else in the State. In the Lehigh, as at the Delaware Water Gap, these shales were classed as combined Clinton and Salina, while the Shawangunk was arbitrarily subdivided into Medina and Oneida.

On the Schuylkill, where the Shawangunk is only 500 feet thick, the Longwood has a thickness of more than 2,600 feet. The section as measured by Doctor Chance was summarized by Lesley as follows:

	Feet
Upper red shale	750
Upper red shale and sandstone	630
Upper olive shales	680
Ore sandstone	96
Lower olive shale	450
	2,606

To this Lesley would add several hundred feet for the eroded top rocks, making the whole thickness about 3,000 feet.

Throughout the region from Culvers Gap, New Jersey, to the Schuylkill Gap in Pennsylvania no fossils have been found in the shales of this series. The sections are terminated by the Lewistown limestone series, which throughout the more northerly portion seems to succeed the shales rather abruptly. In New Jersey and adjoining districts of Pennsylvania these beds have been differentiated into their components and given distinct names. They can with more or less certainty be traced into the New York series, and some of them have also been recognized farther south along the Front Ridge.

In the Delaware Water Gap region the red Salina shales (Longwood) are succeeded by a 5-foot bed of fossiliferous limestone, the Poxino Island limestone of I. C. White. This is followed by the Poxino Island lime shales, which are more or less magnesian, but wholly unfossiliferous and have a thickness of 200 feet. They are in turn succeeded by 90 feet of Bossardville limestone, a gray to blue calcilutyte, well banded and composed of lime mud, most probably derived from the erosion of older limestones. Fossils are scarce in this formation, but those that are known are of Lower Monroe age. The limestone is followed by about 15 feet of greenish shales, which constitute the terminal member of the Lower

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[82] Summary Final Report Geol. Pennsylvania, vol. II, p. 732.

Monroan of this region. Above the shales lies the Croasdale conglomerate and sandstone, between which and the Lower Monroe exists a pronounced hiatus. This sandstone marks the return of the sea in Upper Monroe time, the type of sedimentation being that of the Decker Ferry or early Cobleskill.

At the Susquehanna Gap in Blue Mountain the section is not well enough exposed to give a complete succession. The "Clinton" or nearshore phase of the Niagaran has here a thickness of 989 feet (Claypole). It consists of soft shales, sandstones, and iron ores, a 2-foot bed of the latter being considered by Claypole the top of the formation. Beneath this is a 5-foot bed of "sand rock." Both the sand rock and the overlying ore bed carry Niagaran fossils, Claypole having recorded *Beyrichia lata, Calymmene clintoni,* and *Ormoceras vertebratum* Hall from them. Overlying the upper ore bed are green shales and thin, hard limestone bands containing some fossils, among which Claypole found *Lingula oblonga* Conrad (= *L. clintoni* Vanuxem) and *Beyrichia* (*Klœdenia*) *notata* Hall. These shales are succeeded by 400 feet of red shales, which have been correlated with the Bloomsburg red shales of the region farther north. The shale is on the whole very uniform and fine grained, showing, as do most of the shales of this type, scattered green spots and occasional green layers and seams. Fossils are absent from these beds except in the upper part, where, as will be shown elsewhere, they were subsequently introduced. The series is succeeded disconformably by the Hamilton (Marysville) sandstone, which will be more fully discussed in a subsequent paper.

Elsewhere in Perry County the red Bloomsburg shales are 700 feet thick and are succeeded by 700 feet of variegated red and green shales. Near the top of the variegated shales occurs the Bloomfield (Landisburg) sandstone member, a bed of soft, friable sandstone, varying in color from dull reddish to greenish and in thickness from 10 to 40 feet. It contains an abundance of *Leperditia* cf. *alta,* and has besides furnished some interesting remains of a primitive fish and a fishlike Agantha. The latter is *Palœaspis americana* Claypole and the fish is *Onchus pennsylvanicus* Claypole. The nearest relative of the Palæaspis is *P.* (*Holaspis*) *sericea* Lankaster sp. from the Lower Old Red sandstone of Monmouthshire, Scotland, from which the American species differs only in minor particulars. *Onchus pennsylvanicus,* as represented by fin spines, is a type known from the Siluric and the Devonic, occurring as low as the Niagaran.

The gray shales succeeding are 200 feet thick, and consist of soft argillaceous shales, with occasional harder, more calcareous beds. They contain *Leperditia* cf. *alta,* which often covers entire slabs. It is probable that the dividing line between the red and the variegated shales here marks the line between the Salina and Lower Monroe, or that line may be some distance down in the red shales. In the western part of Perry County (Saville township) this seems to be the case, as shown by the following interesting section (F^2, page 324):

	Feet
Solid red shale (top)	200 +
Greenish yellow shale	2
Red shale and sandstone with fish scales ?	4
Red shale and sandstone	10
Red shale and sandstone with fish scales ?	1
Sandy red shale	3
Greenish yellow shale	1
Soft red shale (almost a soft fossil ore) with *Leperditia* cf. *alta*	3
Red shale (base)	100 +

This section may mean that more than 200 feet of the red strata were reworked when the Lower Monroe Sea transgressed over the old Salina red sediments (Longwood), and that this amount was redeposited as marine Lower Monroan. A similar thing may be indicated by the occurrence of a sandstone bed, the Bridgeport sandstone, about 200 feet below the top of the red shale in Tyrone township. Though only 5 feet thick, its occurrence in an otherwise uniform shale series is rather significant. The "Leperditias" and fish remains may, on the other hand, indicate an interruption of red sedimentation by stream or saline lake deposits.

About 100 feet of Bossardville limestone succeed the gray shales in Perry County, followed by the Clarks Mills beds, 100 to 150 feet thick. These contain an abundance of fossils, all of them of Upper Monroan age and of the eastern type, including *Tentaculites gyrocanthus, Spirifer vanuxemi, Leperditia alta,* etcetera.

The Keefer sandstone.—What seems to be clearly the southwestern extension of this series of formations is seen in the post-Niagaran sandstone shales and limestones of western Maryland and adjoining districts in West Virginia. The basal bed here is the Keefer sandstone, which rests on Clinton, and shows the following succession of beds on the Chesapeake and Ohio Canal, Maryland, at lock 53:[83]

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[83] G. W. Stose and Charles Swartz: Pawpaw-Hancock Folio No. 179, U. S. Geol. Survey, 1912, p. 5.

		Feet
	Soft gray to yellow shale, overlying the sandstone.	
Keefer sandstone.	Hard white to gray sandstone, thick bedded above, thin bedded to shaly below	14
	Hard black fissile shale	1
	Hard sandstone with rough surfaces, stained yellow and red	10
	Hard black shale, sandy at top and pitted by rust-stained worm tubes; contains abundant fragments of a eurypterid close to *Hughmilleria socialis*[84]	6
	Irregular bedded sandstone	7
	Drab to pink shale with thin sandy beds at top.	
	(Clinton)	38

The occurrence of these Eurypterids, apparently identical with those of the Shawangunk grit, is strong evidence for the Shawangunk-Pittsford age of the sandstone, and it may be regarded as the attenuated outer edge of the overlapping series of Shawangunk strata. Eastward in the quadrangle the Keefer sandstone increases to 50 feet, while westward it dies out altogether, occurring only as a thin ripple-marked layer above the eroded Niagaran surface near Cumberland.

The McKenzie formation.—The Keefer sandstone is succeeded by a series of thin limestones and shales which have been classed, together with the Keefer sandstone, as the McKenzie formation by the United States and the Maryland geological surveys. The fossils determined by Ulrich from the fossiliferous beds of this horizon opposite Great Cacapon are as follows:

Dalmanella postelegantula
Trematospira n. sp. (near *T. camura* and *T. perforata*)
Whitfieldella n. sp. (near *W. nitida*)
Spirifer n. sp. (near *S. sulcatus*)
Spirifer cf. *eriensis*
Rhynchonella formosa
Rhynchonella cf. *vellicata*
Rhynchonella n. sp. (very finely plicated)
Unicunulus cf. *pyramidatus*
Ctenodonta n. sp.
Cleidophorus cf. *Nucula sinuosa* Simpson
Prothyris n. sp. and other pelecypods
Coleolus sp. undet.
Othoceras, 2 species undet.
Beyrichia moodeyi
Klœdenia cf. *sussexensis*
Two undescribed species of Klœdenella and prenuntial varieties of *K. pennsylvanica*, *K. turgida*, and *K. clarkei*.

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[84] Clarke and Ruedemann have identified Pterygotus and Dolichopterus ? comparable to *D. otisius*, and carapaces suggesting Hughmilleria.

This fauna has been referred by Stose and Swartz, on the authority of Ulrich, to the Salina, but there is nothing in this association which may not be regarded as representing Lower Monroan. This is indeed strongly suggested by *Spirifer* cf. *eriensis,* the Klœdenia, and Klœdenellas, especially the form compared with *Klœdinia sussexensis* (Weller), which in the Lower Monroe is represented by the closely related *K. monroensis* Grabau, and perhaps by the Whitfieldella, which should be compared with *W. prosseri* Grabau of the Lower Monroe, which is a direct successor of *W. nitida,* suggesting that species in its form and size and differing mainly in the character of the dental plates and the spondylioid muscular area.[85]

Rhynchonella (*Rhynchotrema*) *formosa* Hall is a Helderbergian species and is probably a wrong identification. If *Rhynchospira formosa* Hall is meant, then it is probably identical with *R. præformosa* Grabau from the Greenfield limestone of the Lower Monroe. *Trematospira camura* is a Niagaran form, *T. perforata* a Helderbergian one. *Rhynchonella* (*Uncinulus*) *vellicata* is another Helderbergian form and so is *Uncinulus pyramidatus.* It is plain that this faunal list has little value; if it indicates anything at all it is the Monroan age of the formation. In water-lime beds from the upper part of the McKenzie formation a small tergite and several pieces with Pterygotus sculpture were found.

Conglomeratic limestones above the Keefer sandstone indicate a break in the series, which I believe is filled in by the main mass of the Salina continental deposits farther north.

The McKenzie formation, exclusive of the Keefer sandstone, is about 160 feet thick, and is succeeded by the "Bloomsburg"[86] red sandstone member, which varies in thickness and character from place to place, being 120 feet thick east of Tonoloway ridge. Its character suggests the red Longwood, of which it probably represents a reworked portion. It marks a shoaling or emergence of the Lower Monroe sea-floor and a period of stream deposition. Pseudormorphs of salt crystals occur, indicating a partial return to arid conditions. This may have corresponded to Sylvania deposition in Ohio, Michigan, and Ontario, or may have been earlier.

The succeeding 325 feet of shales and calcareous beds (part of Wills Creek shale) are mostly light colored, containing *Leperditia alta* and other ostracods. These suggest an Upper Monroan age, but are not conclusive. The next succeeding 400 feet of Tonoloway limestones, how ever, carry an undoubted Upper Monroe fauna. This continues for a considerable distance into the overlying limestone, which Ulrich classes with the Helderbergian, but which shows a large percentage of late Monroan species, and is better referred to the Siluric, even though a number of Helderbergian species make their appearance. It is merely a case of a Siluro-Devonic transition fauna.

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[85] A. W. Grabau: Monroe fossils, p. 154.

[86] This is not the Bloomsburg of Pennsylvania, but belongs to a much higher horizon.

Farther west, near Cumberland, Maryland, the whole of the lower as well as the upper Monroe is represented by limestones, which rest with a strong evidence of disconformity on the Keefer sandstone, which in turn lies disconformably on Niagaran. It thus appears as if the southern extent of these mid-Siluric red deposits did not reach the Maryland line, where only the reworked sands occur, which were redeposited in the encroaching Lower Monroan Sea.

Other Salina beds of Pennsylvania.—It is more difficult to differentiate the red deposits of Salina age from the underlying Clinton and overlying Monroan in the counties west of the Front Ridge (Blue Mountain). The Shawangunk is wanting, not having been extended to this region, but red shales abound. How much of these, however, are reworked Longwood, deposited during Monroan time, is not yet ascertained. The most significant exposure of these beds is undoubtedly found in the Bloomsburg anticline or Montours Ridge of Columbia and Montour counties, where the series reaches the surface in a narrow, eroded anticline with steeply dipping sides, the center of which exposes the Clinton formation.

Resting on the upper olive brown shales, limy beds, and flaggy sandstones of the Clinton, we find the Bloomsburg red shale, about 440 feet thick and best exposed in the gorge of Fishing Creek, behind the village of Bloomsburg. The beds are dark red, very uniform, though occasionally sandy, and marked with a few thin layers of green, which apparently show reduction of the iron. No fossils have ever been obtained from the red shales, but from variegated shales near the top of the red beds I. C. White reports a species of Lingula in considerable abundance near Chulosky furnace, on the eastern line of Northumberland County. Thus it appears that the Monroan portion of the series must be carried down a slight distance into the red beds.*

Overlying the Bloomsburg red shale are 407 feet of greenish and gray shales alternating with red shales, sometimes high in iron content (10 to 12 per cent) and with thin beds of magnesian limestone near the top. This is the Middle Salinan series of I. C. White, but must be classed as Lower Monroan. No fossils have yet been reported from this series.

*** These formations are now being studied by Ruth Raeder, candidate for Ph. D. in Columbia University.**

Overlying it are 329 feet of greenish and buff shales, and shaly limestones which I. C. White calls his Upper Salina, but which also must be referred to the Lower Monroe. White reports these beds unfossiliferous, but I have seen indications of fossils in some of them. The series is succeeded by Lewistown limestone, the lower part of which is of Upper Monroe age. Southwestward along the strike the Bloomsburg red shale is less uniform in character. In the Logan section (Mifflin County) several beds of olive shale 5 feet or more in thickness are found intercalated in the red beds, which still maintain a thickness of 432 feet. In the Orbisonia section the red beds are less than 400 feet thick. Finally, in Blair County, the extreme western exposures, less than a hundred feet of the red shales occur interpolated with many layers of gray shale and some limestones. Another series of red beds occurs a hundred feet below, showing similar alternation. Limestones and shales separate the two series and thin-bedded limestones and shales succeed them, capped finally by the Lewistown limestone with Upper Monroe fossils. The whole series is probably referable to the Monroe. There are about 460 feet of mixed strata between the Clinton iron ore and the Lewistown limestone.

Other Salina beds of New York.—Turning now to the north and northwest, we find that along the Shawangunk range the red beds slightly overlap the conglomerate. They are alternating red and green shales and sandy beds, and are generally known as the High Falls shales. Their thickness does not exceed 91 feet, and they are succeeded by the Binnewater sandstone, a quartzose sandstone sometimes slightly reddish and averaging 38 feet thick.* Above this come the limestones of the late Upper Monroe—the Wilbur, averaging 2 to 6 inches; the Rosendale, 15 to 20 feet; Cobleskill, 14 feet; Rondout, 20 feet, and Manlius, 50 feet, bringing us to the top of the Siluric. The limestones overlap in the northern Helderbergs.

Throughout the greater part of the State of New York the Salina begins with the Vernon red shale, except where, as at Rochester, the Pittsford shale forms a transition formation from the Niagaran below. The Vernon shale varies from 150 feet in the type locality to 400 or more in central New York. In the typical outcrop in the town of Vernon near Clinton, New York, it comprises 135 feet of dull red shale unstratified and with green spots scattered through the mass. It is separated by 10 feet of light greenish shale from the underlying Niagaran limestones and by 5 feet of similar shale from the succeeding dark Camillus shale. At Syracuse, where the Vernon shale is 525 feet thick, it is succeeded by the salt beds, this being the general order within the State. Thin sections show the rock to be exceedingly fine grained, consisting of tiny quartz grains embedded in a red matrix of earthy or claylike material.[87] The amount of ferric oxide is only 2.25 per cent and that of ferrous oxide 0.75 per cent, but it is so regularly disseminated that it produces a uniform coloring of the deposit. The green spots, often with black centers, are essentially free from ferric oxide, the analysis giving 1.19 per cent of ferrous iron, which Miller believes is largely present in the form of carbonate. He holds that the presence of organic matter prevented the oxidation of the iron in the spots and in the green shales above and below, and thinks this organic matter may have been sea-weeds. This is at least very doubtful, for no evidence of the neighborhood of the sea has been adduced. The Vernon suggests rather the accumulation of fine loess-like material, chiefly as wind-blown dust. Such a dust may, of course, inclose an abundance of organic substances, such as seeds and spores of land plants, and even low forms of animal life which the wind may carry from distant regions, and which when deposited will by their decomposition locally prevent oxidation.

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* Shaft 4, Rondout syphon, board water supply record.

In the Rochester region, where the Vernon shale has a thickness of 600 feet, it is separated from the Niagaran series by the interesting Pittsford shale, with its remarkable Eurypterid fauna. These deposits and their contained Eurypterid fauna were described in detail by Sarle,[88] who gives the following section in descending order (page 1083):

	Feet	In.
1. Red shale marlite (Vernon)	10	
2. Hard, fine-grained, yellowish dolomite, having an imperfect conchoidal fracture	2	
3. Red shale	1	
4. Break estimated at	3	
5. Dolomite like number 2	3	
6. Green shale or marlite	4	
7. Red shale	1	8
8. Break estimated at about	2	
9. Green shale	2	5
10. Black shale, very fine texture, fossils, and with 1 inch dolomite parting (Eurypterid horizon)	1	6
11. Green shale	1	
12. Dolomite like number 2	2	
13. Green shale or marlite	6	
14. Light colored water lime, some pyrites and sun cracks	5	
15. Pea green shaly marlite	7	
Total	51	7

16. Impure yellowish porous limestone (Niagaran).

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[87] W. J. Miller: Origin of color in the Vernon shale. N. Y. State Museum Bull. 140, pp. 150-156.

[88] New York State Museum Bull. 69, 1903, pp. 1080-1108, plates 6-26.

There are thus 20 feet of strata between the top of the Niagara and the black shales carrying the Eurypterids. The stromatoporoid reef rocks, with an incipient Guelph fauna, were succeeded by thin-layered, impure, ripple-marked dolomites, with "fucoids" as the only common fossil. This was followed by the deposition of tough porous, very bituminous limestone, succeeding to which was formed a stratum of thin-layered bituminous accretionary limestone, forming flat, imbricating, shell-like domes. Then another change resulted in the formation of 2 feet of light yellowish, impure limestone, with indications of a finely branching organism, probably a plant, and followed by a greenish, shaly marlite, which in Sarle's view form the base of the Salina, and carries a small species of Pterinea. The water-lime next succeeding, with its shrinkage cracks, marks a temporary drying up of the region, though marine conditions are still indicated by the occurrence of a Pterinea, a Lingula, a Leperditia, and an Orthoceras. With the exception of the last, these fossils have been found in the black shale layer which is chiefly characterized by the Eurypterid remains. Above this horizon the green shales and dolomites continued for a while and then gave way to red sedimentation.

Among the species found in the black shale *Hughmilleria socialis* Sarle, a species very closely similar to *H. shawangunk* Clarke of the Eurypterid shales of the Shawangunk conglomerate, takes the first rank. It occurs abundantly in the lower half of the black shale, "where it is so prolific that certain planes are literally packed with its remains, making this probably the richest Eurypterid stratum known." Another form, variety *robusta* Sarle, also occurs. The genus Eurypterus, represented by the single species *E. pittsfordense* Sarle, occurs most frequently in the upper half of the shale, just above the limestone parting. The dolomite layers, on the other hand, are almost entirely free from Eurypterid remains, but contain Leperditia, Pterinea, and occasional pentalabiate Gomphoceras. Other species found are *Pterygotus monroensis* Sarle, *Stylonurus multispinosus* Clarke and Ruedemann, *Ceratiocaris præcedens* Clarke, *Emmelozœ decora* Clarke, and *Pseudoniscus roosevelti* Clarke, besides fragments of other species.

The significance of this section will be discussed later, but there are several points to which attention may be called now. It is evident that some marked changes was taking place with the beginning of Pittsford sedimentation. The old fauna, which had existed over this region for a long period of time, was dying out. Temporarily a new assemblage of organisms appeared, whose remains were, moreover, restricted to the black muds, while the dying Niagaran fauna made several attempts to return to the Rochester region. After a while both the Niagaran and the Eurypterid faunas became extinct in this region, and the red sedimentation of the Vernon shale set in. That this was intimately connected with the red shale (Longwood) sedimentation farther east can not be questioned, and it seems equally clear that the Pittsford shale sedimentation corresponded in part to the Shawangunk sedimentation farther east, as shown by the similarity of organic remains.

In Michigan the Vernon shale is absent, or at any rate its earlier phases are represented by salt deposits. As shown by the borings in southeastern Michigan, what appear to be Niagaran dolomites are directly succeeded by salt deposits, the lowest bed here having a thickness of 160 feet[89] in one section. It may, of course, be true that the limestone at the base still belongs to the Salina, but that seems rather questionable. The shales succeeding and separating the different salt beds are not red, so that it appears that Vernon sedimentation did not extend so far.

Interpretation of the sections—The Shawangunk conglomerates.—Considering the deposit as a whole, we see that it has roughly the form of a semi-cone, whose greatest thickness is in the region of the present Kittatinny Mountains in New Jersey and Pennsylvania. From this point it decreases regularly northeastward and southwestward and, since it is absent in southern New York, it must also decrease, probably at a similar rate, toward the northwest. This rate averages 20 feet per mile. Southeastward it seems to decrease at a more rapid rate, as shown by the fact that in less than 24 miles it has decreased from 1,900 to 1,200 feet, or at a rate of about 30 feet per mile. The fact that the formation becomes coarser to the southeast, and that the pebbles are less purely of one kind of material, argues that the source from which they were derived lay in that direction. The same thing is shown by the character of the pebbles themselves, which are mainly vein quartz, and by the abundance of the feldspar, since there is no other rock capable of supplying such material except the crystalline old land on the southeast. Some part of the series might indeed have been derived from the early Siluric and late Ordovicic deposits of a similar character (Tuscarora and Bald Eagle), but the probabilities are that if the eastern folded portions of these strata made any contribution it was a slight one. It must not be forgotten that the center of the Shawangunk deposit is shifted approximately 145 miles to the northeast of the center of the Bald Eagle deposit to a region where the lower series had thinned away to an insignificant sandstone layer.

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[89] Royal Oak Well No. 2. See Lane, Geol. Survey of Michigan, vol. v, pl. xl; also Wyandotte well, pl. xlvi.

That the point of greatest thickness of the Shawangunk marks the debouchure of the stream which brought the pebbles from the old land can hardly be questioned. They could not have been carved from a cliff, unless it were one of pure vein quartz, for otherwise the pebbles would not be of such pure character throughout. To any one familiar with a modern seacoast this need not be demonstrated. Nor would the distribution of the pebbles be such that the deposit is thickest in one point only and thins away in all directions. We should expect relative uniformity in thickness parallel to the shore. Only a river deposit—that is, a river delta—may have the form of a cone decreasing in all directions away from the source of supply by progressive outward overlap, and likewise decreasing *toward* the source of supply by backward overlap. The question next arises, Did this deposit form in an arm of the sea or did it form on dry land? So far as the deposit itself is concerned, *a sea is not necessary*. Just such a deposit could accumulate on dry land. It would have all the lithic and structure characteristics found in the Shawangunk. These are:

First. The decrease in coarseness of material from the center outward, and also upward, since the lowering of the grade, coincident with the enlargement of the fan, would cause the coarser material to be deposited farther upstream.

Second. The abrupt changes in texture from conglomerate to sandstone and back and the irregular extent of the several members. This latter feature is indeed hard to explain on any other hypothesis.

Third. The purity of the pebbles—that is, the similarity in lithic character—which indicates long transportation and destruction of all but the quartz pebbles.

Fourth. The moderate rounding of the pebbles.

Fifth. The abundance of feldspar in the ground-mass, which on a seashore is more apt to suffer destruction, as shown by the studies of Mackie on the sands of Scotch rivers and coasts.[90]

Sixth. The combination of rounded grains, purity of sand, and complex or eolian cross-bedding. The cross-bedding might be caused here and there where a bar is just awash, but the combination of this with the other characters mentioned on the seashore could only be by the merest chance, while it is the expected thing in the case of eolian deposits.

Seventh. The widespread occurrence of cross-bedding of the torrential type throughout the entire visible extent of the deposit from northeast to southwest, a distance of about 200 miles, and from bottom to top, a thickness of 1,900 feet in the center and with all the oblique layers pointing to the northwest. Such a type of cross-bedding has never yet been observed on the seashore, nor is it conceivable how such a type can be formed in subaqueous deposits. This cross-bedding is, however, exactly the type which would be be formed if the deposit in question were formed by torrential rivers.

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[90] Trans. Edinburgh Geological Society, vol. 7, pp. 148, 298, 443. Summarized in Principles of Stratigraphy, where many other illustrations are given.

Eighth. The shale layers. These might, of course, also occur in marine beds.

Ninth. The character of the overlap of the strata which is away from the source of supply. An overlap away from the source of supply may occur in subaqueous delta deposits, but it would invariably be a replacing one—that is to say, while the coarse river-borne detritus is deposited on the shore other purely marine deposits are forming farther away. Now, the base of the series is open for examination for a length of nearly 200 miles, and in no case is there any finer, purely marine deposit replacing the lower coarser detrital beds away from the center. If the deposits were forming in the sea and gradually spreading out, their relationship to the underlying rocks should be as shown in the following diagram (figure 11), whereas the actual relationship is as shown in figure 12, the successively overlapping clastic beds resting directly on the old erosion surface.

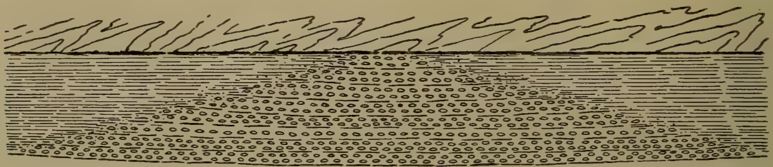

FIGURE 11.—*Diagram showing the Relationship of a Seashore Delta of coarse Clastics and the replacing Overlap*

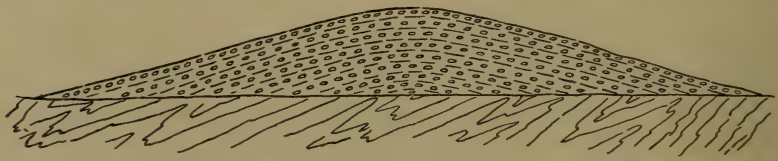

FIGURE 12.—*Diagram showing Diameter and Overlap of a subaerial delta Fan*

Tenth. The absence of undoubted marine fossils.

The argument from contemporary salt deposits and from the occurrence of Eurypterids.—There are, then, none of the lithic and structural characters known to be possessed by the Shawangunk which are not also characteristic of or at least found in torrential deposits formed entirely on dry land. Indeed, it is quite apparent that a number of the most marked characters of the formation are difficult, if not impossible, of explanation on any other theory of origin. Why, then, do we find in the literature the common reference of this conglomerate to an "estuarine" or a "lagoon" or a "seashore" deposit? This is in part no doubt due to the general disinclination to take another of the formations formerly unquestionably regarded as marine out of this category and add it to the growing list of formations now regarded as of continental origin. Some geologists, and apparently not a few, view every such attempt with jealous distrust, and they hold out to the very last for the old accepted, but never proved interpretation long after all the signs in the case point to the necessity of accepting the new. But there are two other reasons in the present case why the marine origin of the Shawangunk conglomerate is held to by so many geologists. The first is that it precedes and is intimately associated with the deposits of salt and gypsum which characterize the Salina group of the interior, and which many geologists are still loath to interpret in any other than the orthodox way prescribed by Ochsenius.[91] The second reason is the recent discovery of Eurypterid remains in the black shales intercalated between the conglomerate layers. Now, Eurypterids have almost always been regarded as marine animals, especially during the earlier periods of their reign on the earth, in spite of the suggestive discussion by Professor Chamberlin, in which it was shown that Eurypterids were more likely inhabitants of fresh water and took to a marine habitat later. It was not that fresh-water Eurypterids were unknown, for beautifully preserved specimens had repeatedly been obtained from terrestrial deposits in close association with coal plants. But it was and is believed by many that the deposit which most satisfactorily preserves these organisms, the Bertie water-lime, *must be marine,* and therefore the Eurypterids must be marine, and therefore all Siluric Eurypterids must be marine, even though they become fresh-water forms in the Devonic, and therefore, finally, all deposits containing Eurypterids before the Devonic *must be* marine.

We may now proceed to look more carefully into these questions and see if the Salina deposits really were marine and if the Eurypterids of the Siluric were necessarily so. If we can establish that in neither case is the marine hypothesis the best one explaining these deposits or accounting for the distribution of these organisms, our last excuse for regarding the Shawangunk conglomerate as a marine deposit falls to the ground.

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[91] See, for example, the recent elaborate discussion of the origin of the Salina salts by Clarke and Ruedemann in the Eurypterid memoir, which does not even mention the desert theory.

The origin of salt deposits.—I have elsewhere[92] discussed at some length the origin of salt deposits and will merely summarize the chief points in this connection.

The ultimate source of the salt is probably in all cases the sea, but the method of abstraction from sea-water varies, while a relative dryness of climate seems to be a necessary requisite. The known methods of separation are (1) complete evaporation, (2) deposition according to the bar theory, and (3) the desert theory of separation. Regarding the first theory—that is, the evaporation of water of an extensive basin and the concentration of the salt in a small area—I have shown that:

"Several facts are to be considered in this method of salt deposition as forming crucial test points for the application of this theory to the elucidation of the origin of an older salt deposit. These are:

"First. Complete evaporation of sea-water furnishes a normal succession of deposits, beginning with gypsum, followed by the sodium chloride and ending with the potash salts. These latter might under circumstances be removed under the influence of desert conditions by the winds.

"Second. Later deposits should be separated from the first by layers of detrital sediment, for it is inconceivable that a flooding of a desert area by the sea should be unaccompanied by a great spread of clastic material over the entire area flooded.

"Third. With the incursion of the sea into this area, the life of the outer oceans will also enter the inclosed sea to exist for a while, until the connection is broken and evaporation again renders the waters too saline for the existence of these organisms. Long before evaporation has proceeded far enough to deposit the salt, these organisms are killed off and their preservable remains become embedded in the clastic strata forming at the bottom of the inclosed basin. Thus the dividing clastic layers would also be fossiliferous.

"Fourth. The sea being near enough to flood the basin at intervals, contemporaneous marine deposits, carrying the remains of the normal marine fauna, which also characterizes the clastic beds between the salt layers, are formed within a comparatively short distance of the salt deposits."

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[92] A. W. Grabau: The origin of salt deposits, with special reference to the Siluric salt deposits of North America. Bull. 57, Mining and Metallurgical Society of America, Feb., 1913. See also Principles of Stratigraphy, chapter ix, where the whole question of modern salt deposits and the various themes of origin are discussed and illustrations cited.

"Applying these criteria to the Salina deposits of eastern North America, we find, first, that while gypsum and salt occur in alternating layers, there is a notable absence of the potash salts such as characterize the great Zechstein salt deposits of North Germany; second, the characteristic separating layers are found as a rule, but, third, they are entirely unfossiliferous, these Salina deposits being noted for their barrenness of organic remains, and, finally, fourth, there are no undoubted marine equivalent deposits carrying the normal oceanic fauna of the time anywhere within reach of the salt deposits. Schuchert, it is true, draws a connection with the Atlantic across northern New Jersey and southeastern New York, but (as I have already shown) it is here that the clastic deposits are thickest, and so there must have been a broad land area still farther east from which the material composing these beds was derived."

"It is thus evident that this mode of formation of salt deposits is not applicable to the Salina deposits of North America."

In considering the deposits formed according to the second or bar theory, we are again "confronted with the fact that such deposits of salts should be fossiliferous, for the amount of marine life destroyed in the Karabugas is enormous, and the accumulation of organic remains in these deposits is unparalleled in the neighboring sea. Again, such accumulations of salt should be in close proximity to deposits formed under more normal marine conditions, for the saline gulf and the sea which supplies the salt water are separated only by a narrow bar. The failure of both these criteria in the Salina formation of North America makes it evident that this method of accumulation could not have been the one to which these salt deposits owe their existence."

The third or desert theory of deposition regards the salt as obtained from the connate sea-water imprisoned in the older marine rocks, together with the additional amount of NaCl absorbed by marine clastics. Analyses have shown that the amount of NaCl in recent marine clastics may be as 8 per cent of the mass of the sediment (see analysis quoted in the paper cited). The connate water alone would furnish an amount probably not short of 1 per cent.

"To form a bed of salt 100 feet thick and covering an area of 2,500 square miles (which is probably more extensive than any single salt layer in the New York or Michigan basins) would require, on the basis of 1 per cent of salt content, the destruction of an older marine clastic formation 10,000 feet thick and covering the same area. The same salt bed might be derived from the destruction of an old marine formation 100 feet thick and covering an area of 250,000 square miles, or an area equal, approximately, to that of the States of Ohio, Indiana, Michigan, Wisconsin, and a part of Illinois. The area tributary to the Salina basins was probably three times the area of these States, or more, and from the remnants of the Niagaran beds left in some localities its thickness averaged at least 500 feet, and may have approached 1,000 feet, not to speak of the underlying marine Ordovicic strata. Thus at least 15 such salt beds could be obtained from the Niagaran beds, a large part of which are known to have been eroded during Salina time. It is probable that half this amount of salt is more than sufficient to form all the salt beds of the Salina basins of New York, Michigan, and Ontario.

"On the basis of the salt content of modern marine deposits the amount of available salt might easily be considered as five times greater than that given by the above calculations.

"The calcareous beds in the Salina series of New York and Michigan are undoubtedly formed from the lime sand and lime mud derived by the mechanical destruction of the older limestones (Niagaran). The magnesian character of some of these beds is accounted for by the partial dolomitic character of the limestones from which they were secondarily derived. The gypsum may, of course, be in part the calcium sulphate of the old sea-water and in part altered limestones of the clastic type. Much of the lime sand and mud remained unused, however, until the advent of the Monroe Sea over this region, when it was deposited as stratified clastics in this sea, or on its margins, to form the finely bedded Monroe strata.

"Considering the Salina deposits in the light of modern salt accumulations, it becomes apparent that of all the known methods of accumulation, that of the continental fits best the conditions found and explains all the characters of the deposits, which, on the other hypotheses of origin, are difficult or even impossible of explanation. One of the strongest arguments in favor of the marine or estuarine origin of the clastic Salina deposits, the Shawangunk and the Longwood, thus falls to the ground, and we are driven to the conclusion that these deposits could not have accumulated in a body of standing water, marine or estuarine, because, as shown by the contemporaneous deposits in the interior basins, where such seas should have been, there was no such water body in existence. Instead of this there was a desert area, parts of which were flooded momentarily by the infrequent stream, which washed the saline efflorescence from the surrounding highlands and thus brought about their concentration in a circumscribed desert area" (page 8).

Relation of the Eurypterids to their environment.—It has been, as a rule, tacitly assumed that Eurypterids were marine organisms, at least in the earlier periods of their existence. The only writer who has argued for a non-marine habitat of these organisms was Chamberlin,[93] whose study was mainly a philosophical one and which only incidentally considered the indications furnished by the rocks in which the remains are found. Nevertheless, here, as in so many other cases, this brilliant writer and investigator has touched upon the essentials of the problem, which he, for the first time, clearly places before us, and he has pointed out the method of attack by which further evidence is to be obtained. It is true that, as Weller has said, ". . . . there is no inherent characteristic of the fossil Eurypterus which can in any way suggest that it may not have been a truly marine organism, and our conclusion that it was not such an organism is drawn from the physical surroundings of the fossil itself, rather than that the physical conditions are what we believe them to be on account of some peculiarity of the fossil."[94] Still, Chamberlin's deduction, that the fish form "could only have developed in water that possesses a persistent and usually rather rapid motion in a fixed direction—*i. e.*, in rivers," must not be overlooked. Our investigations, however, must be directed mainly toward the physical characters of the strata. It is precisely this close analysis of the physical characters of the strata in which the Eurypterids occur, and the interpretation of these characters in terms of origin, that has until recently been so universally neglected. In the description of the species there has seldom been made an attempt to locate them precisely in the formation, to note the state of their preservation, and, above all, to note precisely their association or lack of association with other organisms. The fauna of a whole formation in which Eurypterids occur has been listed, but as a rule one finds no statements regarding the precise occurrence, whether other organisms occur in the same stratum or whether they are restricted to higher or lower strata.[95] In order to get at the foundation of the problem, it has been necessary to search the literature of the world to find out not only how many species have been described, but also their conditions of preservation and their association with other organisms. This work has been undertaken by Miss M. O'Connell, a graduate student in paleontology in Columbia University. She has prepared an abstract of her studies which, though incomplete, embodies all but the rarest occurrences in this field. Miss O'Connell has continued this investigation and endeavored by the study of the museum material, as well as the literature, to trace out, so far as is possible, the precise habitat of the Eurypterids. Her results will be published in the near future.

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[93] T. C. Chamberlin: On the habitat of the early Vertebrates. Journal of Geology, vol. 8, 1900, p. 400.

Distribution and occurrence of the Eurypterids: Summary by M. O'Connell—In general.—The world-distribution of the Eurypterids shows that these merostomes ranged in geological age from the pre-Cambric through the Permic, reaching their acme in numbers, development, and diversity of types in the Siluric. From a careful search through the literature of Europe and America it was found that 17 genera and subgenera and 158 species have been described; 14 genera or subgenera and 63 species of this number are recorded from North America.[96] Considering the species so far described, it will be seen that the lithological characters of the formations in which they are found, the numbers of representatives, and the perfection of preservation are significant factors in the interpretation of the conditions under which the Eurypterids lived.

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[94] Bull. Geol. Soc. Am., vol. 22, 1911, p. 228.

[95] This criticism also applies, though to a less extent, to the magnificent memoir on the Eurypterids of New York just issued by the Survey of that State.

Pre-Cambric.—From the pre-Cambric[97] only one species, *Beltina danai* Walcott, has been recorded. This occurs in the Greyson shales of the Belt Terrane of Montana and the Altyn limestone of the same State; also in siliceous shales of about the same horizon in Alberta, Canada. Both Walcott and Barrell consider the Belt formation non-marine, the beds having been spread out by streams, and partly, perhaps, in fresh or brackish waters, which were rarely in connection with marine waters. Walcott thinks that Beltina, of which thousands of fragments have been found, was swept in from the open ocean during one of the marine invasions, but he also notes the possibility that this type may be related to some fresh-water Branchiopoda. The main points, however, are that the fragments are very numerous, that they occur in a non-marine or brackish water formation, and that no typical marine organisms are found with them. It should in this connection be stated that Clarke and Ruedemann question the merostome nature of the Greyson shale fossils, but admit this for the specimens from the Altyn limestone and the equivalent beds of Alberta, Canada.

Cambric.—The Cambric and early Ordovicic are peculiarly wanting in Eurypterid remains, and what few have been found have been confined to North American formations. In the Middle Cambric there are undoubted marine Merostomata, discovered by Walcott in 1910 in the Stephen shale in British Columbia, Canada. He found many wonderfully preserved specimens associated with trilobites and other marine organisms, thus leaving no doubt as to the marine character of the formation. Two genera are described, Sidneyia and Amiella, the former from very perfect and abundant material, the latter from one broken fragment. These "Limulava," as Walcott has classed them, would offer a strong argument for the original marine habitat of the Eurypterids, were they true Eurypterids. They are not, however, as is seen from a comparison of the Limulava and Eurypterida, and Walcott himself has said that with further study the Limulava will probably be made an order coordinate with the Eurypterida. This is also the position taken by Clarke and Ruedemann (Mem. Eurypt., pages 406-410), who consider that "this order possibly belongs to the Merostomata, but it is distinctly allied to the crustaceans . . . ." and that it is more generalized than the Eurypterida.

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[96] Memoir 14, N. Y. State Museum: The Eurypterida of New York. *Beltina danai* is omitted from the list in this memoir, but is here added.

[97] Since these deposits are disconformably succeeded by Middle Cambric (sometimes perhaps late Lower Cambric) marine beds, I see no reason why they could not be regarded as the continental equivalents of the Lower Cambric marine strata of the regions farther west.—A. W. G.

The only true Eurypterid from the Cambric is *Strabops thacheri* Beecher from the Potosi limestone of Missouri, a formation generally classed as of Upper Cambric age. One almost perfect individual has been found, but it occurs without any other fossil associates in an argillaceous calcilutyte, the origin of which is not proven to be either marine or non-marine, though associated beds carry a good marine fauna.

Upper Ordovicic.—From the Ordovicic until just recently only two occurrences had been noted, that of *Echinognathus clevelandi* Walcott, described from the Utica shale of Holland Patent, New York, where one thoracic appendage and a portion of a thoracic somite were found, and that of *Megalograptus welchi* S. A. Miller, originally described as a graptolite and occurring with a typical marine fauna, chiefly crinoids, in the Liberty or Middle Richmond beds of Warren County, Ohio. The material consists of fragments of walking legs (one nearly complete) and a few body segments. Lately there have been some extremely interesting discoveries of Eurypterids in the Schenectady and Normans Kill shales and sandstones of the Mohawk and Hudson valleys. The preliminary notice of the Schenectady specimens (originally referred to the Frankfort), which has appeared in the report of the Director of the New York State Museum for 1910 (page 31), shows that these remains, "usually in fragmentary condition, abound most freely in fine-grained black shale, intercalated between thick calcareous sandstone beds . . . , but they also occur in the sandy passage beds between the two. The sandy shales are full of organic remains, partly of the supposed seaweed *Sphenothallus latifolium* Hall and partly of what appear to be large unidentified patches of Eurypterid integument. In the black shales the Eurypterid remains are rarer, but their surface sculpture is excellently retained, and here their organic associates are *Climacograptus typicalis* and *Triarthrus becki*. As a result of imperfect retention of these Eurypterids in the rocks where they most abound and their sparseness in the shales which have best preserved them, we are still left in ignorance of the full composition of the assemblage, but it is safe to say genera, species, and individuals were abundant at this early period, and the evolution of distinctive characters . . . had progressed to so sharp a differentiation that we are compelled to carry back farther in history some of the commoner generic designations. These remains in the Frankfort [Schenectady] shale are distributed through fully 1,500 feet of strata off a northeast-southwest coastline in an area of maximum deposition."[98]

Eleven species have been described from the fragmentary material of the Schenectady shale, all of them new. They belong to the genera Eurypterus, Eusarcus, Dolichopterus, Hughmilleria, Pterygotus, and Stylonurus ?. The material consists mainly of cephala, carapaces, and fragments of legs and abdominal segments. Rarely are a few abdominal segments attached to the carapace, while specimens containing parts of legs attached are extremely rare. No complete specimen has been found, the most perfect one being a carapace, with one swimming leg attached and six abdominal segments. This specimen is also partly macerated.* Typical Frankfort material has not yet been recorded, but we may expect to find it at any time.

Still more recently Eurypterid remains have been discovered by Prof. G. H. Chadwick in sandstones of the Normanskill horizon at Catskill, New York:

> "The lithological and faunal conditions at the Broom Street quarry exposures [where these remains were found] were found to be a singularly complete duplication of those of the Eurypterid-bearing exposures in the bluestone quarries at Schenectady. The Broom Street quarry is also a bluestone quarry, the rock being mostly used in the crusher. The courses of 'bluestone' (here an impure argillaceous sandstone) are very compact, from 3 to 30 feet thick between the intercalations of black shales. There is distinct evidence of shallow-water conditions, one bed being conglomeratic and largely composed of pebbles, many of which appear to be mud pebbles; another beautifully exhibiting very regular, widely separated wave marks with winnows of comminuted seaweeds and eurypterids in the troughs.
>
> "Quite as in the bluestone quarries of the Schenectady beds, the surfaces of some of the sandstones are densely covered with rather poorly preserved seaweeds and eurypterids. It was therefore natural to expect that here too the black intercalated shales would contain better material of these fossils and possibly also graptolites that would indicate the age of the beds. They have indeed afforded a layer with an association of finely preserved seaweeds, the eurypterids herewith described, and the following graptolites: *Dicellograptus gurleyi* Lapworth, *Climacograptus bicornis* Hall, *Climacograptus bicornis* var. *peltifer* Lapworth, *Cryptograptus tricornis* (Carruthers), the first three in great abundance. This graptolite association is one of undoubted Normanskill age. The seaweeds occur in large perfect fronds and are of the same type as those in the Schenectady shale. The Eurypterids also are strikingly similar to those from the Schenectady beds."[99]

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[98] Bull. 149, N. Y. State Museum, 1911, pp. 30, 31.

* See plate 85, figure 13, Memoir 14, N. Y. State Museum, part ii.

[99] Memoir 14, N. Y. State Museum: The Eurypterids of New York, by John M. Clarke and R. Ruedemann, pp. 411-412.

The material found in the Normanskill beds is entirely fragmentary, so much so that the generic references are only provisional ones (loc. cit., page 413). These genera are Eurypterus, Eusarcus, Dolichopterus, Stylonurus, one species each, and Pterygotus two species, one doubtfully referred. Five of the six species described are new, but one, *Pterygotus ? nasutus,* has also been described from the Schenectady beds. As a rule, only carapaces are preserved, but several small specimens have a few abdominal segments attached, and one retains a part of a walking leg. Portions of swimming legs and a telson of what appears to be an Erretopterus and one of a Pterygotus also occur.

Summary for pre-Siluric.—Summarizing the evidence for the nature of the habitat of the Eurypterids in pre-Siluric time, it appears that, aside from the occurrence in the Schenectady and Normanskill shales, the evidence seems to be in favor of a habitat not typically marine. In the Belt Terrane the Eurypterid remains are found in fresh or brackish water deposits, showing that in their earliest appearance they were not marine, as is often stated. It may be argued that they were swept in from the open ocean, but if that were the case we may ask: Why are no other marine organisms found associated with the hundreds of Beltina fragments? Moreover, they are found in the lower part of the Greyson shales (3,000 feet thick), which pass into sandstone and conglomerate, indicating a retreat rather than an advance of the sea.[100] As for the Cambric occurrences, the fauna of the Stephen shale, while undoubtedly marine, must be disregarded, since the forms are not true Eurypterids. The one specimen from the Potosi limestone offers no evidence for either marine or non-marine habitat, since the origin of the particular beds in which this specimen occurs is not known. Even if marine, this single occurrence would argue rather against than for a marine habitat of the Cambric Eurypterids. The single fragment found in the Utica shale offers positive evidence against a marine habitat as the normal one. At Holland Patent the fragile graptolites are perfectly preserved in the black Utica shale and the trilobite *Triarthrus becki* is found, with even its delicate appendages intact. Here we have an organism similar in its general structure to the Eurypterids and protected by an exoskeleton identical chemically with that of the Eurypterids, both being of chitin. Why, then, we may ask, if these marine forms are so perfectly preserved, should only a single appendage of a Eurypterid be found? If this form were flourishing in marine waters, why are its remains not found under these ideal conditions for preservation? The same argument would apply to fragments from the Richmond beds of Ohio. This can not, however, be said with reference to the Schenectady and Normanskill shales, except that whole individuals are wanting, and that, though better preserved in the black shales, they are not so common as in the sandy beds. These occurrences, if any, may be considered as pointing to a marine habitat of the Ordovicic Eurypterids, but even here the evidence is extremely unsatisfactory.

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[100] The Altyn limestone shows no positive evidence of marine origin.—A. W. G.

Lower Siluric or Niagaran.—In the undoubted Lower Siluric are several cases of the presence of Eurypterid remains in marine formations. Hall's species of *Eurypterus prominens,* from the Clinton of Cayuga County, New York, was described from a single cephalon, but Whiteaves' *E.* (*Tylopterus*) *boylei,* from the Guelph dolomites of Ontario, is a species founded on a single somewhat crushed, but otherwise nearly complete, individual. An unidentified species of Eurypterus is recorded from the Arisaig of Nova Scotia. These occurrences are in formations containing good marine faunas, but the Eurypterid is represented either by a single fragment or, in the case of the Guelph beds, by a single, though nearly perfect, specimen. One of the most striking occurrences of eurypterids in beds referred to the Lower Siluric (Niagaran) is that in the Kokomo water-limes of Indiana. This has been erroneously referred to the horizon of the Lockport dolomite of New York, whereas it is probably of Lower Monroan age, and from it four species are recorded, namely:

1. *Eurypterus ranilarva* Clarke and Ruedemann.
2. *E.* (*Onychopterus*) *kokomoensis* Miller and Gurley.
3. *Eusarcus newlini* (Claypole).
4. *Drepanopterus longicaudatus* Cl. and R.

The number of specimens known of each of these species is comparatively small, but they are remarkable in showing for the most part the entire individual, though the specimens are rarely perfect. From their apparently macerated character and general preservation it appears that we deal with exoskeletons only, and that these bodies did not live where found, but were transported, though not necessarily from a distance.

The dolomitic water-limes of Kokomo, Indiana, are highly bituminous and some of the beds carry a rich brachiopod fauna, such as *Conchidium colleti* and *Wilsonia kokomoensis.*[101] So far as known, the Eurypterids are restricted to two very definite horizons, while the marine fossils occur in the underlying, dividing, and overlying beds, but not in immediate association with the Eurypterids. With reference to the state of preservation of the Eurypterids, especially of *Eusarcus* (*Eurysoma newlini*)

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[101] Clarke and Ruedemann, loc. cit., p. 99.

(Claypole) in the Kokomo beds, Professor Claypole says: "The condition of the fossils precludes very minute details. They are for the most part merely black impressions on the surface of the gray limestone. In some cases a thin scale can be seen, but it exhibits no structure. . . . The general outline is, however, remarkably sharp and distinct."[102]

A recent discovery of considerable interest in the Lower Siluric rocks of Pennsylvania is that by Professor Van Ingen, of Princeton University, of Eurypterid remains in what appears to be the Tuscarora and associated beds of Swatara Gap, Lebanon County, Pennsylvania.[103] In the beds carrying *Arthrophycus harlani* (?) he found:

1. *Eurypterus maria.* Large and small carapaces.
2. *Dolichopterus* cf. *otisius.* Medium-sized carapace.
3. *Stylonurus myops.* Large and small carapaces.
4. *Hughmilleria shawangunk.* Large carapace.
5. *Pterygotus* cf. *globiceps.* Small carapace.
6. Swimming leg of a Pterygotus or Hughmilleria.

Another bed, labeled 182 B 23, has afforded a carapace not distinguishable from *Eurypterus maria.* In a bed said to occur between a horizon containing what is apparently a Clinton fauna (B 8 x) and one containing a Rochester (or Lockport) fauna (B 19 x), and numbered B 16 h, he found the following remains:

1. Small carapaces, belonging to species closely related to or identical with *Eurypterus maria, Hughmilleria shawangunk,* and *Pterygotus globiceps.*
2. A patch of integument, with finely preserved sculpture, identical with that ascribed to Stylonurus sp. *a.*
3. *Stylonurus myops.* Fragmentary, medium-sized carapace.
4. Coxa, probably belonging to Hughmilleria.
5. Small telson of an Erretopterus.

The earliest European Eurypterid remains are found in the Llandovery (Lower Siluric) of Eastnor Park, England. Fragments of *Pterygotus problematicus* Salter have been found in the May Hill sandstone, or Upper Llandovery, a basal sandstone resting by overlap on various earlier formations, even on the Shineton (Dictyonema) shales at Wenlock Edge. There is everywhere a marked break and unconformity between the underlying beds and the May Hill sandstone, indicating that the latter was the first formation of an advancing sea and may have been a terrestrial deposit reworked. Therefore the fragments of Pterygotus found might just as well be considered to be remains of animals caught in the streams by the incoming ocean as the remains of marine forms. The former supposition seems the more likely, since the Eurypterids are not found in the overlying undoubted marine shales and limestones of Middle Siluric or Wenlock age, though they occur in this horizon farther to the north, where it has lost its typical marine character.

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[102] American Geologist, vol. vi, p. 260.

[103] Discussed by Clarke and Ruedemann, Memoir 14, pp. 418-419.

In early Siluric time six species of Pterygotus have been listed by Barrande from beds of Niagaran or Wenlock age (Ee_1, Ee_2) of Bohemia, and recently Semper has described three more species and one of Eurypterus from the same horizons. The remains are extremely rare and incomplete, but the formations they are found in are in part at least undoubtedly marine. Formtaion Ee_1 is a black graptolite-bearing shale, but these graptolites are found only in certain zones. Ee_2 contains numerous cephalopods, gastropods, trilobites, and corals, and represents in part old coral reefs similar to those in Gotland, to be discussed below. This only serves as another illustration of the imperfect condition in which Eurypterids appear when by any chance they are found in a marine formation.

So far as known, the Wenlock of the Pentland Hills, Scotland, carries the first large Eurypterid fauna of Europe. Sixteen species have been described representing six genera—Eurypterus, Pterygotus, Stylonurus, Drepanopterus, Slimonia, and Bembycosoma. All of the specimens found are in a very fragmentary condition, no perfect individuals having been recorded. The lithological character of the Wenlock of this section indicates that in all probability the formation had a delta origin. The Wenlock is a yellowish sandstone and conglomerate, showing cross-bedding and in some places ripple-marks, and alternating with thin shale beds. This alternation is readily explained in a delta deposit, the shale being subaqueous, the conglomerate and sandstone subaërial or nearly so. If the Eurypterids were marine, they should surely be found in the purely marine equivalents of these beds, the Wenlock limestones of England, as was also pointed out in connection with the May Hill sandstone, but no trace of them has been reported. The evidence would seem to show that the Eurypterids, or perhaps their molted exoskeletons, were brought down by the streams flowing from the land area of northern Scotland into the sea covering England and southern Scotland, the tests being broken and deposited with the sands and conglomerates in the delta beds.

Middle Siluric or Salinan.—In the Middle Siluric of North America are several interesting occurrences of Eurypterids and the first appearance of well preserved individuals. In the Keefer sandstone at the base of the Salina formation specifically indeterminable fragments of Hughmilleria and carapaces of Dolichopterus (cf. *D. otisius*) or Pterygotus have been found along the Pennsylvania-Maryland border.[104] But of far more interest and importance are the faunas of the Pittsford and Shawangunk shales of New York and Pennsylvania. At Pittsford, Monroe County, five species of Eurypterids have been found: *Eurypterus pittsfordensis* Sarle, *Hughmilleria socialis* Sarle, *H. socialis* var. *robusta* Sarle, *Pterygotus monroensis* Sarle, and *Stylonurus* (*Ctenopterus*) *multispinosus* Cl. and R. This fauna is represented by numerous individuals, many of them well preserved, and by many fragments, but typical marine fossils are absent from the shales, although other crustacea, such as *Emmelezoë decora* and *Pseudoniscus roosevelti,* occur. The Eurypterids are here preserved in a remarkable state of perfection. The fauna is found in two layers of the black shales, and the Eurypterids are in such abundance that some layers are "literally packed" with the remains. Marine fossils occur, however, in intercalated dolomites. In a loose block belonging to beds regarded as representing the Pittsford horizon, 3 miles south of Clinton, New York, several specimens of *Eusarcus vaningeni* Cl. and R. were found. "The block is also full of Linguas and Orbiculoideas. . . ." Clarke and Ruedemann think that this may be the adult of *Eusarcus cicerops* of the Shawangunk. From the shale beds in the Shawangunk conglomerate at Otisville, Orange County, New York, a large fauna of Eurypterids has been obtained, but other fossils except Ceratiocarids are absent. The perfect specimens are all of young individuals, some being 2.5 millimeters long, but large individuals are represented only by fragments. The species recorded are:

1. *Eurypterus maria* Clarke.
2. *Eusarcus* ? *cicerops* Cl.
3. *Dolichopterus otisius* Clarke.
4. *D. stylonuroides* Cl. and R.
5. *Stylonurus* (*Ctenopterus*) *cestrotus* Cl.
6. *S.* (*Ctenopterus*) sp. α, sp. β, sp. γ.
7. *S. myops* Cl.
8. *S.* sp.
9. *Hughmilleria shawangunk* Cl.
10. *Pterygotus globiceps* Cl. and R.

The Eurypterids occur in thin bands of black shale intercalated between the grit layers, which bear no traces of the fossils. "While the Eurypterus faunas of . . . Pittsford consist almost entirely of mature and adolescent individuals, the younger growth stages prevail in the Shawangunk grit shales and large individuals are represented only by fragments, which indicate that they may have been destroyed by the more turbulent water conditions." [105]

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[104] Pawpaw-Hancock Folio, U. S. Geol. Survey Atlas.

In the middle portion of the Shawangunk conglomerate of the Delaware Water Gap sections similar black shales have furnished Eurypterids. These were discovered by Mr. Paul Billingsley, of Columbia University, who collected a large amount of material. Prof. Gilbert Van Ingen and Mr. J. C. Martin also obtained material from this horizon, from which Clarke and Ruedemann were enabled to recognize numbers 1, 3, 7, 9, and 10 of the list of species found in the Shawangunk of Otisville. Mr. Billingsley reports[106] that the fragments are all dissociated, the carapaces commonly occurring by themselves and dissociated from the abdominal segments, as if rearranged by violent currents.

Upper Siluric or Monroan.—The Upper Siluric, both in this country and in Europe, shows the best and most typical development of the Eurypterids. In the Lower Monroan (Put-in-Bay dolomite), a marine formation, occurs one species, *Eurypterus eriensis* Whitfield (= *E. microphthalmus* Hall, according to Clarke and Ruedemann), but there are only a few dissociated carapaces and one abdomen. Associated with these in the same bed are small brachiopods (Spirifer, etcetera). The Bertie water-lime of Upper Monroan age contains the largest number of species of any one formation in the world, namely, thirteen[107] species, referred to the five genera: Eurypterus (5 species), Pterygotus (4 species), Eusarcus (1 species), and Dolichopterus (3 species). The specimens are for the most part wonderfully well preserved, but other organisms are extremely rare. In the Museum of the Buffalo Society of Natural Sciences occur a few specimens of marine organisms obtained from the formation which has furnished the Eurypterids. These are two specimens of a long, slender Orthoceras (*O. undulatum*), but the fossils are crushed, macerated, and more or less worn, and they were apparently brought into the Bertie deposits from outside marine waters. The whole aspect of the fossils shows that the animals did not live where the remains are found. Associated with these are a number (six) of well preserved shells, which have been described as *Discina grandis*. These, however, belong to the genus Hercynella, a pulmonate gastropod which may as readily be referred to fresh as salt water. On a large number of the slabs containing

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[105] Clarke and Ruedemann, loc. cit., p. 105.

[106] Manuscript deposited in Columbia University.

[107] The original number described was 23, but many of these have been shown by Clarke and Ruedemann to be synonyms of other species.

Eurypterid remains there occurs an abundance of plants, referred to *Bythrotrephis lesquereuxi.* The habitat of this plant is unknown, but if marine it certainly did not exist in deep water, but was most probably similar in habitat to the eel-grass of the modern shore. The phyllocarid, *Ceratiocaris acuminata,* is of fairly common occurrence, and at Waterville, New York, a small scorpion, *Proscorpius osborni* Whitfield, probably a terrestrial form, has been found perfectly preserved. A remarkable fact[108] in connection with the occurrence of the Eurypterids in the Bertie water-lime is their distribution in two distinct basins or pools, the "Herkimer pool" on the east and the "Buffalo pool" on the west. These "pools," while prolific in species and individuals, have, however, only two species in common, so far as published data show. Further search may reveal more common forms, but it is certainly a significant fact that the common species of the two areas are distinct, when the horizon is the same and the localities only a few hundred miles distant. The following lists give the species for each pool,[109] representative or identical species being apposed:

Herkimer pool,	Buffalo pool.
1. *Eurypterus remipes*............	1. *Eurypterus lacustris*
	2. *E. lacustris* var. *pachychirus*
	3. *E. pustulosus*
	4. *Eusarcus scorpionis*
5. *Dolichopterus macrochirus*......	5. *Dolichopterus macrochirus*
	6*a*. *D. siluriceps*
6*b*. *D.* (?) *testudineus*	
7. *Pterygotus macrophthalmus*.....	7. *Pterygotus buffaloensis*
8. *P. cobbi*........................	8. *P. cobbi*
	9. *P. grandis*
10. *Proscorpius osborni*	

"The species common to both are *Dolichopterus macrochirus* and *Pterygotus cobbi,* both of which are quite rare, while the predominant species in both places are unlike. It is not believed that these differences necessarily express distinct stratigraphic horizons, as both lie near the top of the water-lime succession, but rather indicate original regional separation into distinct lagoons or pools . . . which we may assume to have been synchronous. There is, in the face of the difference suggested, a certain degree of approximation in the two, expressed by such vicarious species as *E. remipes* and *lacustris, P. macrophthalmus* and *buffaloensis,* which may well mean distinctions due to geographic isolation. The

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[108] Clarke and Ruedemann, loc. cit., p. 92, foot-note.

[109] Ibidem.

Herkimer pool is well restricted and its faunule can not be traced very far toward the west; the Buffalo *E. lacustris*, however, appears alone as far east as Union Springs, Cayuga County, and as far west as Bertie, Ontario. Another difference in these faunas is the preponderating great size of all the species in the Buffalo pool and, by contrast, the small size of and abundant young among the Herkimer County species. . . . That the smaller creatures lived in conditions of shallower water is evinced by the sun-dried and cracked rock surfaces of their matrix, while such evidences are wanting in the Buffalo pool."[110] . . . Another striking fact is the total absence of Eurypterids from the Rosendale cement rock, which is essentially the same type of rock and of the same age as the Bertie, lying, as does the Bertie water-lime, just below the Cobleskill. The Rosendale, however, occasionally contains marine organisms and is immediately preceded as well as succeeded by fossiliferous marine limestones. *Eurypterus remipes*, the common form of the Bertie water-lime in the Herkimer pool, just below the Cobleskill, has also been obtained from the Rondout water-lime above the Cobleskill at Seneca Falls, Seneca County, New York. This clearly shows that the Cobleskill marks only a temporary marine invasion between two periods during which water-limes were forming and during which the same species of Eurypterids were preserved in these water-limes. From a horizon believed to be near the Bertie at Selins Grove Junction, Pennsylvania, some fragments of Eurypterus like *E. remipes* have been obtained, and from a lower horizon, probably in the Lower Monroe (upper part of the McKenzie formation) near Hancock, Maryland, fragments suggesting a Pterygotus have been reported.

In the highest Siluric horizon of North America, the Manlius limestone of New York, a single species of Eurypterus, *E. microphthalmus* Hall, has been found. The type, a separate carapace, was obtained from a boulder near Cazenovia, Madison County, New York. A nearly perfect specimen was obtained from a drift boulder near Syracuse, New York, also referred to the Manlius. Several carapaces were obtained from the Manlius *in situ* near Litchfield, Cranes Corner, Herkimer County, and at Manlius village. "From this it appears that there is a continuous water-lime bed near the top of the Manlius formation extending from Onondaga County to Albany County and the species seems to be confined to this layer."[111]

The Ludlow or Upper Siluric of England and Scotland shows a good representation of Eurypterids, there being altogether 4 genera and 21 species. The remains are described chiefly under the genera Eurypterus and Pterygotus, there being, however, an abundance of perfect specimens of *Slimonia acuminata* Salter from Lanarkshire and one poor specimen of *Stylonurus logani* Woodward, with some doubtfully determined fragments of *S. powriei* Woodward. There are twelve species of Eurypterus found mainly in the upper beds of the Downton sandstone and occurring in some cases also in the Passage beds to the Lower Old Red sandstone. The remains are fairly numerous, but nearly always imperfect, there being sometimes one almost perfect representative of a species and then a great many small broken pieces. Some of these are closely similar to American species belonging to the genera Eusarcus and Hughmilleria (Clarke and Ruedemann, page 94). These Upper Ludlow sandstone and grit beds, with the Bone bed forming the top and followed by the Ledbury shales, the Downton sandstone, and the Tilestones, have been interpreted by Geikie as a series of formations indicating a change from marine to land conditions. Eleven species of Pterygotus have been found in various members of the Ludlow group, mainly in the upper part. Between the Downton Castle sandstone and the underlying beds is a grayish layer, sometimes black with vegetable remains, and this contains Pterygotus, fresh-water fish remains—forerunners of the Old Red fishes—and numerous Crustacea. The species of Pterygotus are in a very much better state of preservation than are those of any of the other genera found in these beds. That so many species of Pterygotus, including many well preserved individuals and an even larger number of fragments, should be found in this layer, which is often black with vegetal remains and contains, besides, fresh-water fish, is indeed significant. The species *Pterygotus problematicus* Salter, already mentioned as occurring in the May Hill sandstone, is also reported from the Upper Ludlow rock of Ludlow, England, from the Ludlow Bone bed at Ludlow, the Downton sandstone at Kington, and the Base of the Old Red at Ludlow, but it is probable that this species, represented only by fragments, has not such a wide range, the identification of the fragments being incorrect. Geikie notes that "vegetable remains, some of which seem to be fucoids, but most of which are probably terrestrial and lycopodiaceous, abound in the Downton sandstone and Passage beds into the Old Red sandstone. The Eurypterid genera still continue to occur, together with phyllocarids (*Ceratiocaris*) and vast numbers of the Ostracod Beyrichia (*B. klœdeni*). Prevalent shells are *Lingula cornea* and *Platyschisma helicites*. The Ludlow fishes are also met with."[112] Geikie, furthermore, considers the occurrence of Eurypterids and fresh-water fish as an indication of the change from marine to non-marine conditions.

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[110] Clarke and Ruedemann, loc. cit., p. 92.

[111] Clarke and Ruedemann, loc. cit., p. 194.

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[112] Text-book of Geology, 4th edition, p. 961.

The Baltic provinces of Russia and Scandinavia have become famous for their Siluric sections, particularly the ones exposed on the islands of Oesel and Gotland. Considering Oesel first, two species of Eurypterus have been reported, *E. laticeps* Schmidt, from two fairly perfect head shields, and *E. fischeri* Eichwald, from many excellent individuals. The latter is a very close relative of the American *E. remipes*. There is also an abundance of fragments of *Pterygotus osiliensis*. The bed in which these occur is a fine water-lime, very much like the Bertie, with undoubted marine beds above and below it, but the bed itself contains only the Eurypterids just mentioned, in association with a large number of scorpions, which were probably land animals, and certain merostomes, classified by Woodward as Eurypterids, but now included under the Synxiphosura by Zittel and others. Such forms are: *Pseudoniscus aculeatus*, one good specimen at least; *Bunodes lunula, B. schrenckii*, and *B. rugosus*, including some fragments and a few well preserved individuals, and *Exapinurus schrenckii*. In Gotland similar conditions are seen to prevail. Although the sections in the northern and southern parts of the island have been studied separately and correlations are not as yet complete, still one important fact has stood out for the whole island: there is everywhere a great break between the Lower and Middle Gotlandian (Siluric). That there was at this time a retreat of the sea and a subsequent advance has been indicated in many places. In the north around Visby a detailed section has been worked out by Hedström. The upper meter of his division III of the Gotlandian consists of marl shales and limestones, with *Pterygotus osiliensis* and *Palæophonus nuncius* Thorell and Lindström as the characteristic fossils. Lindström has called this the Pterygotus marl, and it is seen to lie just at the top of bed III. Then follows a break and above the disconformity is bed IV, a conglomerate with water-worn gastropoda and portions of *Spongiostroma holmi* Rothpletz. The Eurypterid beds here occupy lagoon areas between coral reefs of early Siluric age, and thus the association of Pterygotus and scorpions with marine forms may well be accounted for, since the sea would have occasional access to the lagoons. Munthe has described a similar break in southern Gotland between the Burgsvik sandstone (Lower Ludlow age) and the overlying oölite (of Aymestry age). The sandstone shows cross-bedding of the eolian type and is followed by the oölite, which is at most one meter thick, grading off into nothing in places and which rests with a disconformity on the sandstone. Holm states that the conditions above the oölite were those of dry land. In the southeast of Gotland, at the Lau Canal, the oölite is represented by a Pterygotus-bearing marl. Thus in Oesel and Gotland the Eurypterid beds are nowhere typically marine, but always of a peculiar nature, either lagoon or else along lines of break marking a change of conditions from marine to non-marine or vice versa. Moreover, the Eurypterids are always found associated with scorpions. In Galicia and Podolia extensions of the Oesel zone occur, with a few remains of the Eurypterids. A single fragment of Pterygotus has been reported from the Upper Siluric of Australia.

Devonic.—With the Devonic throughout the world comes a sudden drop in the number of remains found. There are 95 species in the Siluric, as compared with 17 in the Devonic. There is no doubt that the Old Red sandstone of Great Britain is non-marine, even though in Russia and north Germany it grades into marine beds. In the lower part of the Old Red are found eight species of Eurypterids, all associated with fresh-water fish and plant remains. With the exception of the three Pterygotus species, there are only fragments found. *Pterygotus anglicus* forms a notable exception, for there are numerous well preserved specimens of this species, which ranges in length up to 5 or 6 feet and is always associated with the Old Red fishes. A few fragments of *Eurypterus hibernicus* Baily have been reported from Ireland in the Upper Old Red associated with land plants (*Archœopteris, Sphenopteris,* etcetera), fishes, and a fluviatile or lacustrine mollusk, *Amnigenia jukesii.* In the Upper Devonic sandstones of Condroz, Belgium, *Eurypterus lohesti* Dewalque and *E. ? dewalquei* Fraipont are found associated with animals and land-plant remains.

In North America the pure marine sediments of Devonic age, deposited in the very places where in Bertie time the water-lime was deposited, do not carry a single Eurypterid, while in the Siluric there had been an ever increasing number of species and of individuals, giving a total of 36 species for the whole period. In the Devonic, on the other hand, there are few representatives in the Lower and Middle Devonic of the interior region, and it is not until the top of the Upper Devonic that these remains are found again in numbers. The American representatives of the Lower "Old Red," the Gaspé sandstone and related formations of Campbellton and Dalhousie, New Brunswick, have furnished fragmentary specimens of Pterygotus and other types. A fragment of Pterygotus has been obtained from the Grande Grève limestone of the Lower Devonic of Gaspé. Fragments of *P. atlanticus* Cl. and R. occur in the higher Devonic beds of Campbellton, New Brunswick. Other fragments have been reported from the Knoydart formation of Arisaic, Nova Scotia, where they are associated with remains of Pteraspis and Cephalaspis. This horizon may be of Upper Siluric age. The Portage sandstone of Yates County, New York, has furnished a specimen of *Stylonurus* (?) *wrightianus* (Dawson). A number of fragments of Stylonurus, originally described as *Stylonurus excelsior* by Hall and which Beecher used in making the restoration, which he called *Stylonurus lacoanus*, have all been united by Clarke and Ruedemann under the species *Stylonurus* (*Ctenopterus*) *excelsior*. There are only two specimens, one a complete carapace from the Catskill beds at Andes, Delaware County, New York, and another more fragmentary carapace from the same formation in Pennsylvania. *Eurypterus beecheri* Hall, described from the Chemung of Pennsylvania, has proved to be the same as *Stylonurus beecheri*. George F. Matthew has described some very doubtful fragments as *Eurypterella ornata* from the plant bed number 2 of the Little River group in the Devonic (probably Carbonic) of New Brunswick, but Clarke and Ruedemann have been unable to identify the material. Aside from the species of the Little River group, there are only four identifiable species known from the Devonic of North America.

Post-Devonic.—The only Eurypterids from the Mississippic are four species of Eurypterus from Great Britain and one from the Waverly of Pennsylvania. *E. scouleri* Hibbert was described from Kirkton, West Lothian, where it occurs associated with fishes, stems, leaves, fruits of Lepidodendron, calamites, and other plants. The beds, too, are rich in Entomostraca, and particularly in the fern *Sphenopteris affinis*. Woodward, speaking of this formation, says that it is "a fresh-water deposit, and abounds in bands of silex, alternating with calcareous matter, and presents all the appearance of having been deposited by thermal waters during the Carboniferous epoch." From Eskdale, Scotland, one well preserved, but doubtfully identified species, *Eurypterus scabrosus* Woodman, has been reported. Peach describes two species, *Glyptoscorpius perornatus* and *G. caledonicus* Salter (originally described by that author as *Cycadites caledonicus*, a plant fragment), from the Calciferous sandstone series near Cockburnspath, on the Scottish border, a formation equivalent to the North American Mississippic. The American species, *Eurypterus approximatus* Hall and Clarke, comes from Devono-Mississippic transition beds, if not actually from the Chemung.

With the Carbonic we approach the extinction of the Eurypterids. Five species from North America and seven from Great Britain and

Germany are known. Four species of Eurypterus are found in the Coal Measures of Pennsylvania; one, represented by fragments, in Nova Scotia, and *E.* (*Anthraconectes*) *mazonensis* in fragmentary condition in the Coal Measures of Mazon Creek, Illinois. Particular attention should be called to the occurrence of *Eurypterus mansfieldi,* which Hall has figured,[113] showing the specimen just as it was found lying on ferns in a very perfect state of preservation. In fact both the Eurypterus, of which there are many individuals, and the ferns are so well preserved that it is evident that neither animal nor plant could have been transported far, but that both must have been buried in or near the very place where they had lived. There is now little doubt that these Coal Measure beds are non-marine, so that the five Carbonic species of Eurypterids from North America can be added to the non-marine ones of the previous periods. From the Coal Measures of Europe are reported *Arthropleura armata* Jordan, a fragment in the Saarbrücker Schichten in the middle Upper Carbonic of Germany, and *A. mammatus* Salter, from fragments at Pendleton Colliery near Manchester, England. Jordan has also recorded fragments of *Adelophthalmus granosus* from the Saarbrück beds. All of these are non-marine. A single species of *Eurypterus* (*Edonvillei defima*) has been found in the Rothliegende of Portugal associated with *Walchia pinniformis* and *Sphenophyllum therun* in a typical non-marine formation.[114]

Review of the evidence.[115]—Reviewing the distribution of the Eurypterids as outlined above by Miss O'Connell, we are impressed with the fact that the sediments and their faunas indicate that it is only under peculiar conditions that the Eurypterids are found in abundance and perfection and never under normal marine conditions. Omitting from consideration the merostomes of the Middle Cambric beds described by Walcott, as they are not Eurypterids, we have only the striking occurrences of these organisms in abundance in association with typically marine forms in the shales of the Hudson series in the Mohawk and Hudson valleys. In the Mohawk Valley the shales have been determined to be the shore equivalent of the Trenton limestones farther west, while the beds furnishing the Eurypterid remains near Catskill in the Hudson Valley are shown by their associated graptolites to be of Normanskill age.

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[113] Second Geological Survey of Pennsylvania, Report of Progress PPP, pp. 23-35, pls. 3-8, especially pl. 4.

[114] Clarke and Ruedemann, loc. cit., p. 112.

[115] By the author, a more elaborate discussion of this subject will appear in Miss O'Connell's paper. Part of her conclusions are here made use of, the subject having been under repeated discussion between us in the preparation of her memoir during the past two years.

This latter was originally considered Lower Trenton, then Black River, and finally Upper Chazy. I have elsewhere[116] discussed the age-relations of the Normanskill, and have shown that its equivalency must be with the transgressional portion of late Chazyan (including Black River) time. This is of interest, in view of the fact that the Eurypterids of the Schenectady beds are close relatives of the Eurypterids of the Normanskill, there being at least in one case specific identity. These occurrences Clarke says represent ". . . a purely marine basin, where sedimentation went on rapidly in an Appalachian depression."[117] . . . It will at first glance seem that we have here an undoubted marine occurrence, but closer inspection reveals the fact that all is not as satisfactory as it might be. By the courtesy of the State paleontologist, I was permitted to view the collection of the Schenectady Eurypterids, and I was especially struck with the fragmentary character of the exoskeletons, since illustrated in the magnificent memoir on the Eurypterids. Plenty of carapaces and abdominal segments and separate leg parts occur, and now and then a number of body segments in conjunction, but not a whole individual was to be seen. The Normanskill material is equally fragmentary; ". . . few legs and telsons have been found in connection with the carapaces and fragmentary abdomina."[118]

This is certainly remarkable, in view of the fact that the Eurypterids occur entire elsewhere, and that entire specimens of *Triarthrus becki* are found. Certainly we can deal here only with cast-off exoskeletons which were dismembered and not with buried entire individuals. Where were the individuals that furnished these exoskeletons? A significant fact lies in the greater rarity of these fossils in the black mud, where they are better preserved than in the sandy beds. This is equally true of the Normanskill and of the Schenectady beds. The sandy beds certainly represent shore-derived clastics, and indicate a stronger supply of terrigenous detritus and swifter river currents than is the case with the muds. In the Normanskill beds there is distinct evidence of shallow water in the conglomeratic beds, full of what appear to be mud pebbles, and in the wave-marks and winnows of comminuted seaweeds with the Eurypterids in the troughs. That the fragments should be most abundant when the lithic character of the rock suggests the greatest inrush of land waters carrying detritus is certainly a most significant fact. It seems to point directly to the land waters as the source of these fragments. It is hard to escape the conclusion that we are dealing with material rafted from the land and deposited near the seashore. It is not impossible that the so-called sea-weed Sphenothallus, which also appears to be abundant in the Normanskill beds, was a land or fresh-water plant; its occurrence in these same beds is not without significance. The presence of Graptolites might at first suggest that the black muds were of deep-water origin, but such is not necessarily the case. The Graptolites are generally fragments, and might just as readily have been cast up onto a mud-flat surface as hydroids at the present time are cast up on mud flats which are exposed to the air often for long periods. The shales may just as readily have constituted the submerged portion of a delta or confluent series of deltas, which received drainage on the one hand from the land and on the other was covered by the wash of the sea. These shales occasionally show mud cracks, indicating that they accumulated in shallow water.

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[116] Outlines of Geological History Symposium, p. 56 ff.
[117] Loc. cit., p. 31.
[118] Clarke and Ruedemann, loc. cit., p. 413.

If land derived, the Eurypterid fragments of the Normanskill and Schenectady beds must have been washed into the Ordovicic Sea before any part of the Bald Eagle delta now preserved was formed, but there is no reason for believing that such land-derived deposits were not forming earlier. Indeed, the character of the Hudson beds shows that such was the case throughout Ordovicic time; that streams coming from the high land of Old Appalachia poured their waters, laden with sand and mud, into the shallow Ordovicic Sea. Such streams could readily bring with them the shed exoskeletons of animals living in their upper reaches and deposit these with the sands and muds on the shallow ocean floor. If this interpretation of the evidence is correct, we should expect to find Eurypterid remains throughout the Hudson series, and we should especially look for them in intercalated shales in the Bald Eagle delta and the Oswego sandstone. We feel confident that future discoveries will substantiate this interpretation and will bring to light additional evidence pointing to the river habitat of these organisms.

Turning now for a moment to the earlier abundant occurrence of Eurypterids in the Belt Terrane, we find that these organisms, if they are Eurypterids, occur alone, without the association of marine organisms. Since the beds in which these remains are found are known from other characters to be non-marine in origin, the only rational conclusion that can be arrived at is that these animals were of non-marine habitat. It certainly would be stretching a point to make them marine and have them washed into the area of continental sedimentation, especially as no other marine organisms occur in these strata.

The isolated occurrences of Eurypterids in marine strata may be neglected, since their very isolation makes them of little value in arriving at a correct conclusion regarding the habitat of these Merostomes. Such isolated occurrences, if they represent scattered distribution, are in reality best explained as cases of individual carapaces washed from the land out to sea, and thus they would become evidence for, rather than against, the non-marine habitat of these creatures. The recent discoveries of Eurypterid remains in the basal Siluric beds of the Swatara Gap region in Pennsylvania is of great significance, in view of the fact that this period, as already set forth, was one of strong land drainage and abundant wash of clastic sediments by the rivers of the old Appalachian land into the sea. The rivers which were able to erode the old Taconic Mountain folds of eastern Pennsylvania and carry the resulting material into the sea were certainly able to wash out during flood time an abundance of the shed exoskeletons of Merostomes which inhabited their quieter reaches.

The most significant occurrence of Eurypterids in the Siluric of North America is in the Pittsford shales and the Shawangunk conglomerate of Salina age and in the Bertie water-lime of Monroan age.

The Pittsford shales have already been cited as deposited during a period of change from open sea, in which limestones and dolomites were forming, to conditions favoring the deposition of red shales. The occurrence of fossiliferous dolomites between the shales carrying the Eurypterids indicates an oscillatory condition, a repeated reassertion of the marine conditions before their final disappearance; for the occurrence of these abundant remains of Eurypterids at this horizon and not before shows that the marine conditions preceding were unfavorable to the existence of these Merostomes in this region, or at any rate not encouraging. That they existed somewhere is shown by the sporadic occurrence of fragments or individuals in the Niagaran limestones of New York and Canada, by the Pennsylvania occurrences, already referred to, and especially by the remarkable examples found in the Kokomo water-limes of Indiana, now correlated with the Lockport horizon.* The latter occurrence might again be cited as evidence for the marine habitat of these creatures were it not for the fact that they occur in beds of peculiar character, intercalated between beds of normal marine type, and by the further fact that the remains are those of cast-off exoskeletons floated into this region, as abundantly indicated by the appearance of these fossils. The Kokomo water-lime was a deposit similar in origin to the Bertie, and the discussion of that formation will also apply with slight modifications to the Kokomo occurrence.

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* This corrlation is, however, rejected by Kindle and others. So far as I have seen the marine Kokomo fossils, they are of Monroan types.

With these facts in mind, we may ask the pertinent question, Where did this great colony of Eurypterids originate? If this was a lagoon or an estuary and the Eurypterids constituted an estuarine fauna, this must have been derived either from the sea or from the land waters. Estuarine faunas, though possessing characters of their own, can be composed only of animals derived from one or both the contributing realms, the sea or the land. No one would assert that a lagoon or estuarine fauna comes suddenly into existence with the appearance of the restricted water body; that it has no progenitors in the sea or in the land waters which combine to form the estuary. And yet it has generally been thought sufficient to refer to these organisms as estuarine or lagoon types, with the tacit assumption that that explained their presence. Clarke, speaking of the Eurypterids of the Shawangunk, says that "our present knowledge of the habits of the Merostome crustaceans, derived from both the living and fossil forms, indicates the shallow water or barrachois origin of all sediments in which these remains abound,"[119] but he does not discuss the origin of this fauna, which he himself considers as normally absent from the sea.

It is evident that the Pittsford and Shawangunk deposits are intimately associated in origin. Essentially the same species of Eurypterids occur in the black shales of both, and the Pittsford can only be regarded as the westward extension of the Shawangunk deposition. This is further shown by the fact that in both cases red shale deposition follows the Eurypterid beds. The Eurypterids of the Shawangunk shales are very fragmentary, only the youngest individuals remaining intact. Billingsley has observed, furthermore, that the fragments are much dissociated; that the cephala, for example, are by themselves as if swept together, while elsewhere the body segments occur. Young individuals are extremely numerous, and these are as a rule well preserved. In the Pittsford shale, on the other hand, the exoskeletons are commonly preserved in a good state of perfection. This might at first seem an argument for the existence of the Eurypterids in the waters in which the remains are so well preserved. We might ask, Why is it, if the Eurypterids were swept by the rivers from the land, that the entire specimens were carried out into the lagoons which existed before the final withdrawal of the sea, while only comminuted remains and young individuals were embedded in the black muds of the supposed river delta? In attempting to answer this, let us assume, for the sake of argument, that the Eurypterids are river animals. During periods of flood the molted exoskeletons of old and young alike are swept seaward by the swollen rivers, which in their bottom portions will roll along sands and pebbles, while the Eurypterid exoskeletons and the fine mud are held more or less in suspension. If the water enters a lagoon or arm of the sea, in which wave activity is slight, these exoskeletons will sink to the bottom with the muds brought in by the flood and will become buried in the mud layers. Over the delta and the floodplains of the distributaries the muds will settle as the waters subside, and with them the exoskeletons will sink to the bottom. Finally, these muds become exposed to the air, are dried, crack and crumble, and are blown about by the winds, and at a subsequent flooding they are rearranged by the waters and finally covered by coarser sediments. During this process the larger exoskeletons must of necessity suffer more or less dismemberment, which the young ones readily escape by virtue of their small size. The skeletons which were swept into the lagoons escaped this destruction because the general absence of waves prevented the rearrangement of the sediments and the consequent destruction of the remains.

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[119] New York State Museum, Bull. 107, p. 303.

There is another fact which must be considered in this connection, namely, that the abundant inpouring of fresh water into the lagoon may have at times transformed it into a brackish or even fresh water body. The Gulf of Finland is almost a fresh-water body, especially near its head, while the Baltic as a whole has a surface salinity of 7.8 permille, though the volume salinity is 10 permille. Compared with the normal salinity of sea-water, 35 permille, the influence of abundant impouring of fresh water is at once seen. During an earlier period the sea was entirely excluded from the Baltic and the fresh-water Ancyclus Lake replaced the Baltic. After the cutting off of the head of the Gulf of California by the building of the Colorado delta, the abundant inpouring of fresh water by that river converted the original salt body (with oceanic salinity of 35 permille or over) into a fresh-water lake of greater elevation and extent, in which an abundant fresh-water fauna existed. The diversion of the river water to the gulf, and possibly an increase in aridity, caused the fresh-water lake to concentrate once more into a salt-water body, this time, however, isolated and probably lifeless. Finally, through continued desiccation, the present depressed desert was produced, with the concentration of the salt in the center of the old sea-bottom. The influence of streams on the salinity is shown in the Black Sea, which has a salinity in the upper 40 or 45 meters of 18.3 permille, while the Sea of Marmora has a surface salinity of 22 to 25 permille and the Mediterranean the normal of 35 permille or over. The Sea of Azov, a shallow homohaline epicontinental body, has an average salinity of 11 permille, but in the northeast, where fresh-water streams enter the basin, the salinity may be as low as 7 permille. Seasonal variations is shown in the Adriatic, where in the spring, when the land waters pour in abundantly, the salinity sinks to 18 or even 16 permille in the neighborhood of the land, while in the winter the salinity is 38 permille even at the mouths of streams.*

It can not be doubted that the great deposits of clastic sediments seen in the Shawangunk formation implies a great influx of fresh water from the land. If the late Niagaran or early Salina Sea was restricted into a lagoon-like body, as is generally conceded, this body must at times have suffered extensive reduction in salinity even to complete freshening. Certainly if this sea was at any time cut off from the ocean, it must have been converted into a fresh-water lake, in which the Eurypterids may have flourished. Without, therefore, attributing to these creatures excessive euryhalinity, we may conceive of their having flourished in abundance in the early Salina basins, which, however, if they were cut off from the sea, must have been fresh-water lakes as long as the great land streams poured into them. Increased aridity, brought about by a rising in the land on the east, would dry the streams near their headwaters or cause them to dwindle away after the manner of modern streams in arid regions. The fresh-water lakes would then suffer desiccation and finally be replaced by salinas, in which no life could flourish. The remarkable fauna associated with the Eurypterids in the Pittsford shales might well be taken as indicative of fresh-water lake conditions, while the intercalated marine layers may be taken as indicating periodic destruction of the barrier and incursion of the sea, with consequent extermination of the rich lacustrine fauna.

We must now turn to a consideration of the rich Eurypterid faunas of the Bertie water-lime. From their finely preserved state, one is tempted to hold that this was the region where these organisms flourished. Indeed, Clarke and Ruedemann expressly consider that the two "pools" of New York—the Buffalo and Herkimer pools—constituted the area of extreme development of these creatures, the latter being especially characterized as the breeding area of these types. We may approach the discussion of this problem from the side of the organisms themselves, scrutinizing the remains and the other organic contents of the rock in an attempt to solve their bionomic conditions of existence, and again we may approach the problem from the side of the sediments, attempting to determine their source and mode of deposition.

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* For further details, see Principles of Stratigraphy, chapter iv.

Taking the organisms first, we find that the specimens, though well preserved, appear to represent chiefly exoskeletons. Clarke and Ruedemann give it as their opinion that "probably the majority of the remains found are the cast exuviæ from the frequent moltings of growing individuals." Secondly, there is a remarkable absence of other organisms which could have served as food for these creatures. True, remains of some plants, apparently aquatic, of Ceratiocarids and of a few entire gastropod shells are found. There seem to be, however, no indications of organic remains which could have served these Arachnids for food, nor does the water-lime anywhere show evidence of broken shells or skeletons other than the Eurypterids. In texture and presumably in origin, the water-lime is exactly the same whether Eurypterids abound or are wholly absent, as in the Rosendale section. Unless these creatures lived on shell-less organisms which have left no remains, this could not have been their habitat, for we can hardly assume that they were purely cannibalistic. That the "pools" were almost if not quite lifeless is shown by the scantiness of other than Eurypterid and Ceratiocarid remains. In the Buffalo pool, besides the plant remains, occurs an occasional Lingula or Leperditia, which probably were washed in from the open sea, as was perhaps the case with the four examples of dead orthoceras shells found. The only fossil besides the Eurypterids represented by a number of specimens are shells of *Hercynella buffaloensis* O'Connell* (identified as *Discina grandis* in the collections), which is regarded as a pulmonate gastropod and may have belonged to the river fauna, though it, too, may have been washed in from the sea. The Herkimer pool has furnished evidence of the proximity of the land in the occurrence of a scorpion, the *Proscorpius osborni* Whitfield with the Eurypterids.

But by far the most marked faunal peculiarity of the Bertie is the separation into two distinct pools, as noted above. As shown by the quotation from Clarke and Ruedemann given in Miss O'Connell's summary, the faunas of these two pools are distinct, having only two of the rarer forms in common. How can such a segregation of species be accounted for? Clarke and Ruedemann consider that the difference is due not to differences in horizon of the two series, but has rather a geographic basis, bringing about isolation of these faunas. How can we conceive of such segregation on a sea-border or in lagoons open to the sea? It must be remembered that this is not an ordinary case of local marine provinces, for first of all the entire order of the Eurypterids is virtually restricted to these pools and absent in the corresponding deposits like the Rosendale, which are more open to the sea. Again, the fauna is a limited one, with typical marine organisms only sporadically represented. How is it possible that marine organisms, which could migrate only along a coastline, should be so distinct in adjoining pools with similar bionomic conditions? Moreover, if these lagoons were peopled from the sea, how it is that there is not an accompanying typical marine fauna, such as always inhabits lagoons and estuaries? The existence of these pools in such close proximity to each other, with distinct faunas, seems to me to be fatal to the hypothesis of a marine habitat of these Merostomes. Per contra, however, this separation is precisely what we should look for if the organisms were river forms. We have an excellent illustration of this in the river trout of western United States. The Columbia and Missouri rivers interlace at their headwaters, and here we find the cut-throat trout, *Salmo clarki*. Away from this headwater region the species become gradually differentiated. Thus the nearest relatives of *S. clarki* are *S. virginalis*, in the basin of Utah, and *S. stomias* of the Platte River. "Next to the latter is *Salmo spilurus* of the Rio Grande, and then *Salmo pleuriticus* of the Colorado. The latter in turn may be the parent of the Twin Lakes trout *Salmo macdonaldi*. Always the form next away from the parent stock is onward in space across the barrier."[120] It is easy to see that river organisms thus gradually differentiating as they separate along the different waters under the influence of isolation might be swept into adjoining basins from two distinct rivers and so be buried as distinct faunas, yet having relationship through a common ancestor. We can readily understand that the *Eurypterus fischeri* of the Baltic provinces might have its near relative in *E. remipes* of the Herkimer region, while this in turn has a close relative in *E. lacustris* of the more western Buffalo region if the river systems in which these species lived interlaced at their headwaters. Such relationship could be understood also for organisms migrating along the coast, but such migration could hardly be accomplished by organisms primarily at home in lagoons which are unfavorable to other marine life.

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* Manuscript in preparation by Miss O'Connell.

The preservation of these Eurypterids in the water-limes reminds us forcibly of the marvelous preservation of the land and marine organisms in the Solnhofen beds of Bavaria. Walther[121] has shown that these organisms did not live in the lagoons in which the fine deposits of lime mud were forming, but were allochthonous—that is, transported from without. They were carried here as dead organisms or quickly expired, and their remains were rapidly covered by the constantly accumulating lime mud, probably stirred up at the time these bodies arrived, and quickly settling again and so entombing the remains. It is precisely in this manner that I assume that the Eurypterids and Ceratiocarids of the Bertie water-lime were buried, the fine lime mud being brought in by the rivers which swept the Eurypterid remains basin-ward.

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[120] D. S. Jordan: The origin of species through isolation. Science, n. s., Nov. 3, 1905, p. 547.

[121] Johannes Walther: The Solnhofen Plattenkalke bionomisch betrachtet. Festschrift zum 70ten Geburtstage Haeckel's.

If the Eurypterids of the Bertie and of the Hudson shales can be satisfactorily explained as river animals swept out to sea, or into basins where conditions of preservation were especially favorable, nothing further need be said about the Eurypterids of the other horizons, both in America and Europe, for those admit of ready explanation on the hypothesis of a river origin. The occurrence of these remains in the lagoons behind the Gotlandian barrier reefs, associated with scorpions as well as marine organisms; their presence in the evident delta type of deposit of Wenlock age in Scotland and northern England, and their absence from the purely marine Wenlock deposits of western England point equally strongly with their occurrence in the Old Red deposits to a river habitat. That such a habitat was the unquestioned one in the Carbonic only adds the final links to the long chain of evidence which to an unprejudiced mind must clearly demonstrate the fluviatile and perhaps lacustrine habitat of life of these remarkable arthropods.

It remains now to be shown that the peculiar sediments which formed the water-limes are in harmony with this theory. The remarkably fine and uniform character of the lime mud composing these sediments has led some to assign to them a chemical origin. Against such an origin, however, all its lithic and structural characters protest. The material is clearly a clastic lime mud deposited in quiet and shallow water uninfluenced by waves. This is shown by the fine stratification and by the mud cracks and other evidences of shallow water. The lime mud was clearly not derived from organic sources, since nowhere in the series is there an accumulation of organic lime in the form of reefs or shell heaps capable of furnishing this fine mud. It is, furthermore, a demonstrable fact that life conditions had not yet reappeared in any marked degree in the region of former salt deposition. Under these circumstances it must be apparent that the older limestones of the Siluric land were the only possible source of the lime mud, unless some unknown factor enters into the calculations here. That these limestones, the Niagaran and underlying Trentonian, were perfectly able to furnish the lime can not be questioned. Disintegration of the exposed surfaces during the arid

Salina period had prepared the material for the rivers to sweep into the basins of deposition. Some of this material was swept into the Salina basin during the intervals of salt deposition and so formed the dividing dolomitic bands. But the bulk of the lime sand and lime mud produced by mechanical disintegration and erosion of the old Niagaran limestones of the Siluric land was utilized to build the fine-bedded Upper Siluric or Monroan strata, of which the water-limes are the most marked examples. If more lime mud and sand is furnished to a river than it can take into solution, the surplus must be carried away as mechanical detritus and deposited where the river currents are checked. If this is in the sea, well stratified calcilutytes inclosing marine organisms will be formed; if in a playa lake, finely stratified deposits free from marine organisms result. This latter I believe to have been the conditions under which the Bertie water-lime was deposited. A series of shallow basins above sealevel, but near the coast, were flooded by the waters of the rivers, which brought large quantities of fine lime mud. With this lime mud were brought at certain times the cast-off exoskeletons of the Eurypterids and Ceratiocarids which inhabited the upper reaches of the rivers. Near the margins of these basins grew reedlike vegetation, the remains of which are often found in these deposits. Finally, pulmonate gastropods (Hercynella), living among these reeds, were occasionally entombed. Once or twice the sea may have broken into these basins, washing with it a couple of dead orthoceras shells and the shells of a few Lingulas and perhaps some ostracods. Even this is doubtful, since the Orthoceras and Lingula shells may have weathered out from the older limestones of the land and become transported into the Buffalo basin, where they were found. The same is true of the Leperditias, though these may actually have inhabited the waters of these basins. In any case, the presence of these few marine organisms is readily explained and offers no barrier to the general acceptance of the theory of origin here outlined. This seems to accord best with all the known facts, whereas the commonly accepted theory of a marine origin of these sediments and faunas meets with insuperable difficulties and requires special hypotheses at every step to bolster it up.

The composition of the Bertie water-lime is in harmony with the idea of its origin from the Lockport and Guelph dolomites, containing 20.35 per cent of magnesium carbonate and 42.75 per cent of calcium carbonate.[122] The presence of 11.48 per cent of silica and 17.5 per cent of alumina also indicates that the material is land derived, that there is a commingling of the muds derived from the erosion of the purer dolomites with the mud obtained from older siliceous sediments. Eastward the chemical character of these deposits changes in the reduction of the amount of magnesium and silicate of aluminum. Here the source was most likely the purer Trenton limestone, and the deposits were formed near the open sea. The Trenton limestone beds, which covered much, if not all, of the Adirondack region at that time, and which were exposed by the erosion of the covering Hudson strata during Salina time, form an admirable source for the water-limes and the greater part of the Manlius limestone of eastern New York. These late Siluric strata merge southward into open sea limestones of organic origin (Lewistown limestones of Pennsylvania), which, during periods of marked transgression (Wilbur, Cobleskill), extended into the region where the terrigenous lime muds were being deposited.

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[122] From analyses of Buffalo water-lime made for Lewis J. Bennet.

Of special interest in this connection is the fact that the genera and species of the Eurypterids are peculiarly long lived, and as such do not form exact horizon markers. Thus the same species seem to have existed in the same region from Normanskill to late Trenton time, and from the beginning of Niagaran time (Medina-Clinton) to the beginning of Salina (Shawangunk), or perhaps better, end of Guelph time.[123] This is not unlike the persistence of characters in modern river crayfish. Thus the *Cambarus primævus* Packard of the Green River beds (Eocenic) of Wyoming is a close relative of the modern *C. affinis* of the same region. This persistence of species in the same watercourses is in strong contrast with the modifications which they undergo as they enter different regions, where, presumably, they are cut off from constant intercrossing with the parent stock. With river organisms, geographic dispersion seems to be conducive to specific modifications, but persistence in a given region during a long period of time seems to bring with it a persistence of type.

Conclusions regarding the origin of the Shawangunk and Longwood deposits.—Having now shown that the salt deposits of the Salina are best explained on the hypothesis of desert conditions without connection with the sea, and that Eurypterids are river rather than marine animals, we have no longer any excuse for withholding our recognition of the subaërial or deltaic origin of these two deposits. The Shawangunk was formed as a delta by streams coming from the highland of Appalachia, in the region now forming southern New York and northern New Jersey, and spread out northward, westward, and southward to the borders of the contracted Niagaran Sea, in which the last survivors of the marine Guelph types existed. Besides some of the river-borne sediment, innumerable carapaces and perhaps many living Eurypterids were carried into this sea, which at times may have been converted into a fresh-water body. With continued aridification of the climate, owing probably to a progressive rise of the old-land region and a further obstruction of the moisture-bearing winds from the east, the interior water body was completely evaporated and its salt content laid down in the deeper depressions. Continued aridity permitted the deposition of the oxidized muds and oxidized sands now forming the red sandstones and shales, while salt and gypsum derived from the leaching and disintegration of the old marine sediments were accumulating in the central basin. This period was brought to a close by the transgression of the Upper Siluric or Lower Monroan Sea from the general region of Maryland southward and westward. A part of the Salinan red sediments was reworked and incorporated as marine sediments with ostracods, etcetera, in the Lower Monroan, which elsewhere is a pure clastic lime-mud rock. The Camillus shale of New York may, in part at least, belong to this period. Finally, in Upper Monroan time, open connection with a southern sea in the Pennsylvania and Maryland region permitted the extensive growth of the Stromatopora and coral reefs with their attendant clastic deposits. These extended into Michigan and probably joined a similar transgression of the Pacific from the northwest. The peculiar basins in which the Bertie water-lime was forming belong to this period, and they were eventually superseded by the extended transgression of the sea, which made the widespread development of the Cobleskill formation possible. The Manlius-Lucas epoch succeeding marks the widespread reestablishment of marine conditions in North America.*

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[123] The Pittsford shales, since they contain the last of the Guelph sediments, might just as well be united with the Niagaran as a closing deposit. The deposition of the Shawangunk in the east probably commenced before Guelph deposition in the interior had come to an end.

It should be noted that the clastic deposits of the Upper Siluric period still denote a general arrangement of easterly winds, and of high lands on the eastern border of the continent to intercept them, and the consequent prevalence of arid or semiarid conditions on the western slopes of this land. A fact which may have considerable significance is that the centers of deposition had shifted to the northeast, having been in Tennessee and in central Pennsylvania in Upper Ordovicic time, but in northern Pennsylvania in Upper Siluric time. In Upper Devonic time one or more of the centers became shifted still farther to the north, though an additional center seems to have persisted in Pennsylvania. Finally, in Mississippic and Carbonic time, a southward migration of the centers of deposition set in again. The discussion of these facts, together with the details of the deposits involved, are reserved for a subsequent paper.

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* These marine transgressions and the changes during the succeeding periods are fully discussed in the monograph on the Devonic Formations of Michigan, now nearing completion.

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JAN 6 1914

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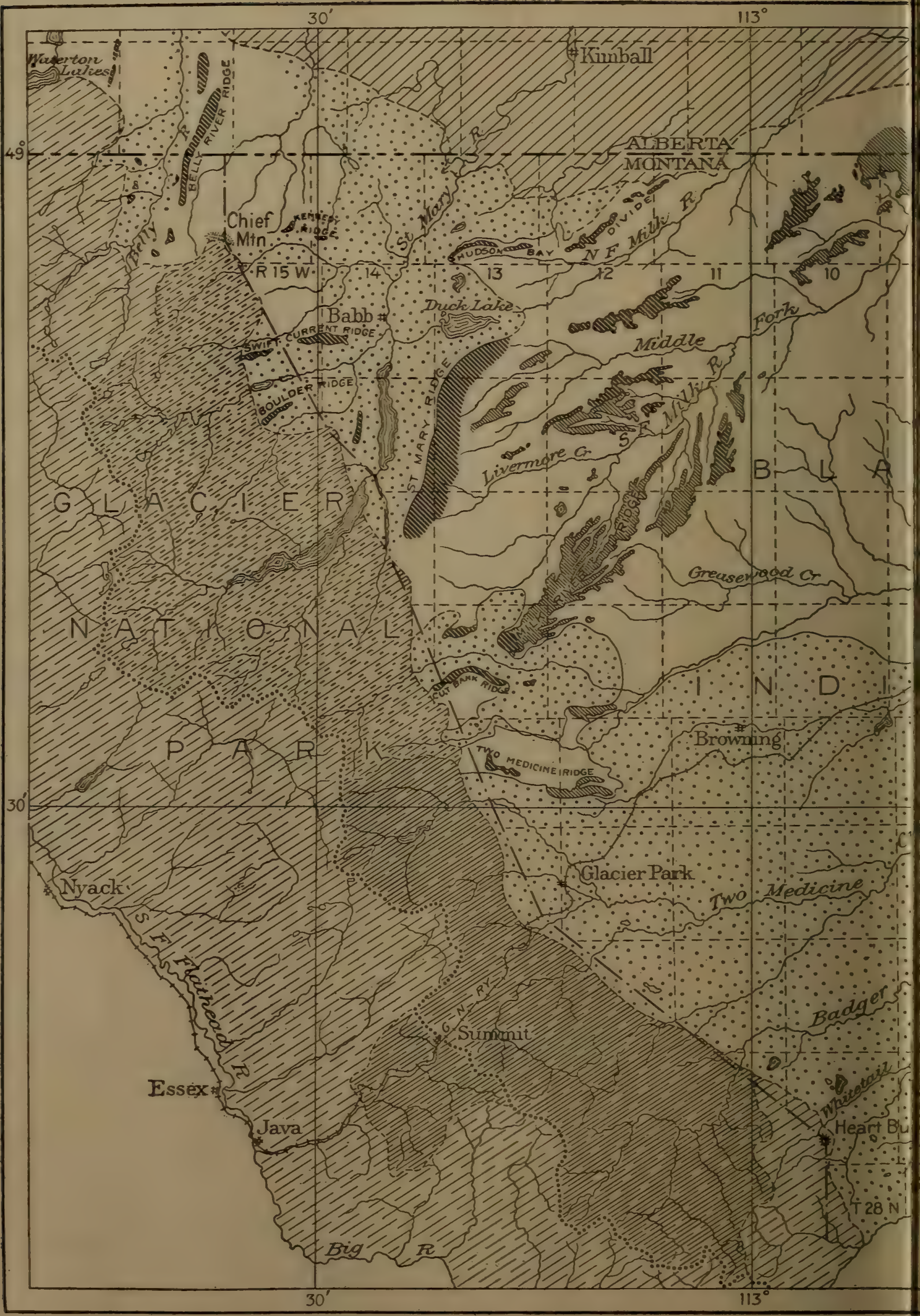
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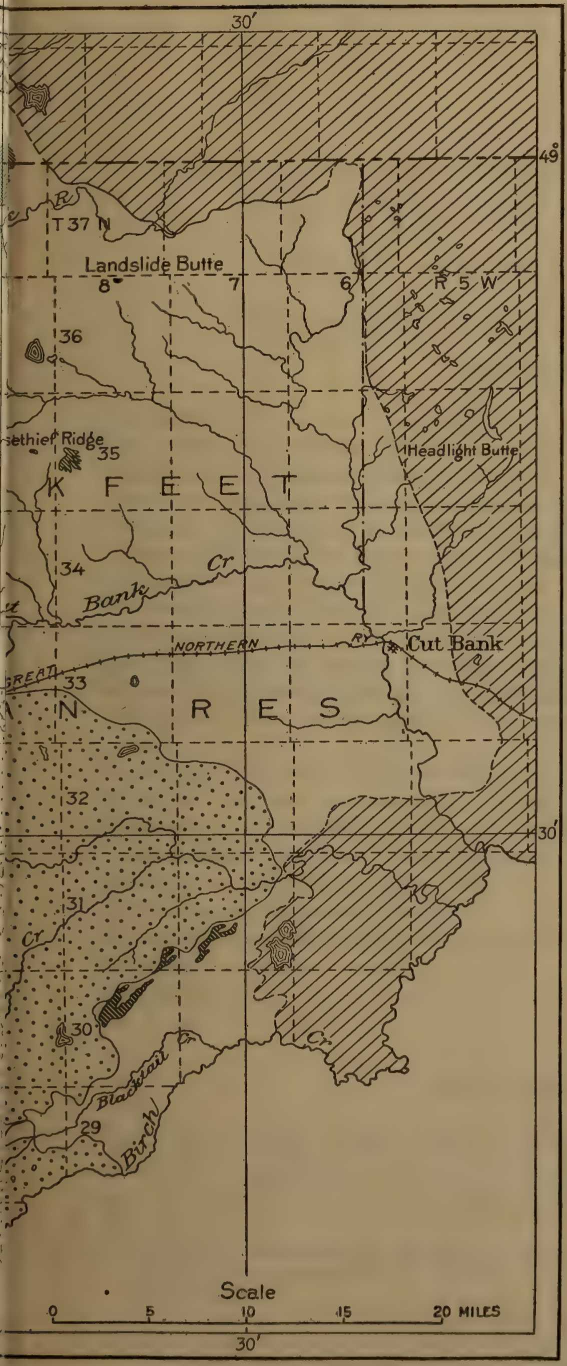
MAP OF PLEISTOCENE DEPOSITS ON PLAINS BORDERING THE ROCKY MOUNTAINS IN THE

By William C. Alden and Eugene Stebinger, U. S. Geologica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LEGEND

▨ High mountain area dissected by many deep glaciated valleys with numerous small existing glaciers.

┆ Continental divide.

▨ Catchment basin of main part of Two Medicine Glacier of Wisconsin stage of glaciation.

⁘ Deposits of mountain glaciers of Wisconsin stage in valleys and on the plain east of the mountain front (mapping not complete).

▨ Deposits of Keewatin ice-sheet of the Wisconsin stage of glaciation. (Boundary in part from F. H. R. Calhoun.)

▨ Deposits of pre-Wisconsin glacial drift and associated gravel capping high ridges whose tops are remnants of the second (lower) peneplain (mapping not complete).

▨ Catchment basin of glacier which extended northeastward onto Blackfoot peneplain at a pre-Wisconsin stage of glaciation.

▨ Deposits of pre-Wisconsin glacial drift and associated gravel capping high ridges whose tops are remnants of the highest or Blackfoot peneplain (mapping not complete).

ION OF GLACIER NATIONAL PARK, MONTANA

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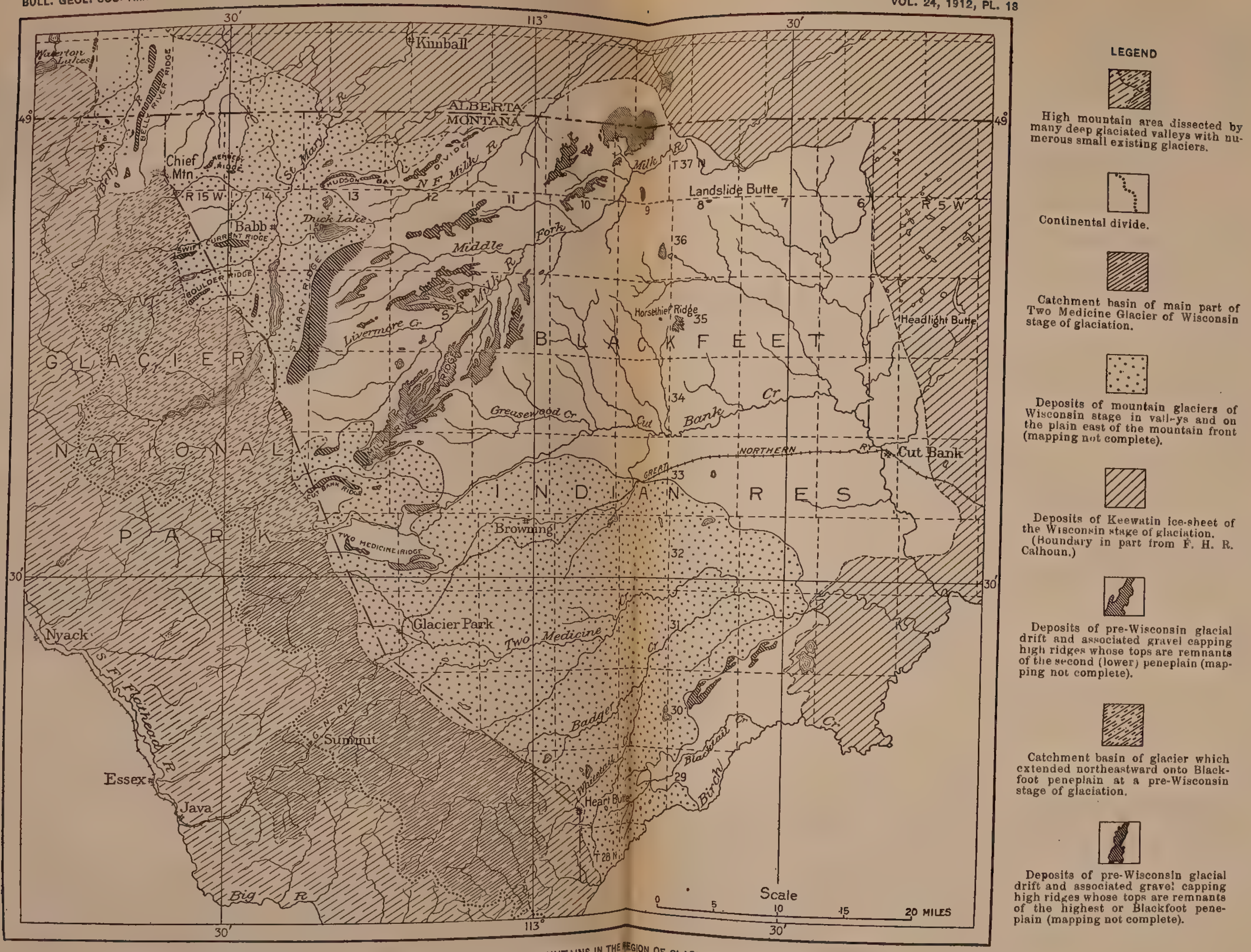
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Milk R.
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Duck Lake
Swift Current Ridge
Boulder Ridge
St Mary Ridge
Middle Fork
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Headlight Butte
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G L A C I E R
N A T I O N A L
P A R K
34
Greasewood Cr
Cut Bank Cr.
Milk River Ridge
Cut Bank Ridge
Northern
Great
Cut Bank
33
I N D I A N R E S
Browning
Two Medicine Ridge
32
Nyack
Glacier Park
Two Medicine Cr
31
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G. N. Ry.
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LEGEND
High mountain area dissected by many deep glaciated valleys with numerous small existing glaciers.
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MAP OF PLEISTOCENE DEPOSITS ON PLAINS BORDERING THE ROCKY MOUNTAINS IN THE REGION OF GLACIER NATIONAL PARK, MONTANA

By William C. Alden and Eugene Stebinger, U. S. Geological Survey, 1912

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PRE-WISCONSIN GLACIAL DRIFT IN THE REGION OF GLACIER NATIONAL PARK, MONTANA[1]

BY WM. C. ALDEN AND EUGENE STEBINGER

(*Presented before the Society December 30, 1912*)

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INTRODUCTION

At the meeting of this Society in December, 1911, the senior author presented a paper under the same title as that above.[2] In that paper it was set forth as having been determined in the preceding summer that

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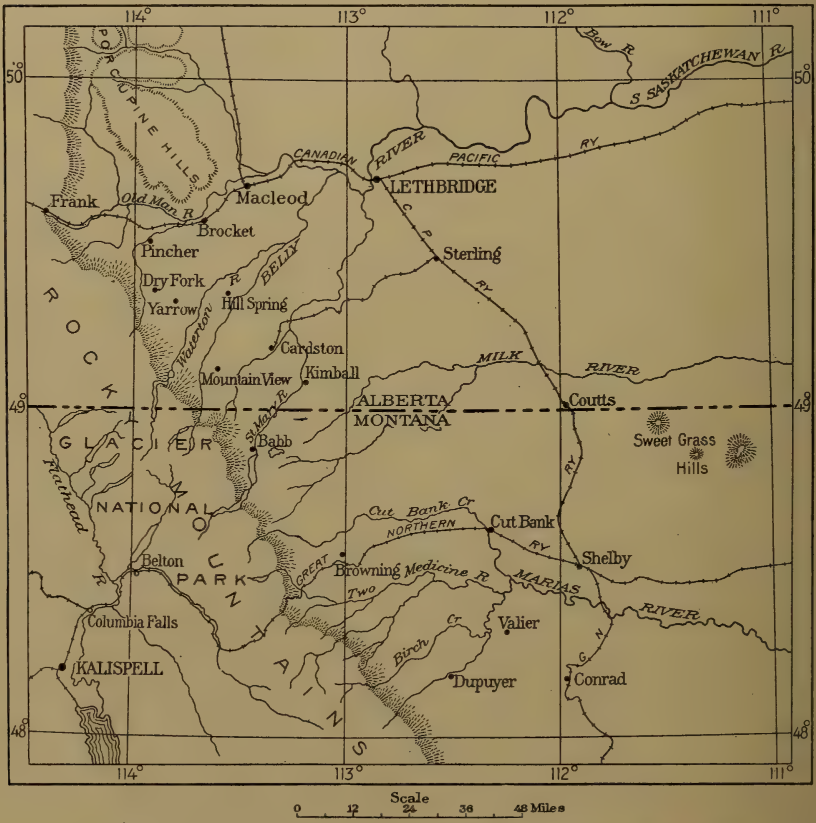
[1] Manuscript received by the Secretary of the Society March 19, 1913.
Presented by permission of the Director of the U. S. Geological Survey.
Second paper.

[2] Wm. C. Alden: Pre-Wisconsin glacial drift in the region of Glacier National Park, Montana. Bull. Geol. Soc. Am., vol. 23, 1911, pp. 687-708.

JAN 6 1914

the high flat-topped ridges of Cretaceous rocks east of the Rocky Mountain front in the region of Glacier Park, Montana, are capped with deposits of glacial drift which, because of its topographic relations and surficial modification by weathering, was regarded as much older than the drift in the intervening valleys. The valley drift was deposited by the mountain glaciers at the time of their last extension, which is regarded as having been practically coincident with the Wisconsin stage of continental glaciation. At that time, in 1911, the extension of the high-level drift eastward from the mountain front and its relations to the quartzite gravels, described by Calhoun, Dawson, and McConnell, as found to the eastward, had not been fully determined, neither was it known what was the relation of this pre-Wisconsin drift to the "Albertan" drift of Dawson.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Cardston
Mountain View
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St. Mary R
Sterling
MILK RIVER
ALBERTA
MONTANA
Coutts
Sweet Grass Hills
ROCKY MOUNTAINS
GLACIER NATIONAL PARK
Flathead R
Babb
Cut Bank Cr
GREAT NORTHERN RY
Cut Bank
Shelby
Browning
Two Medicine R
MARIAS RIVER
Belton
Columbia Falls
KALISPELL
Valier
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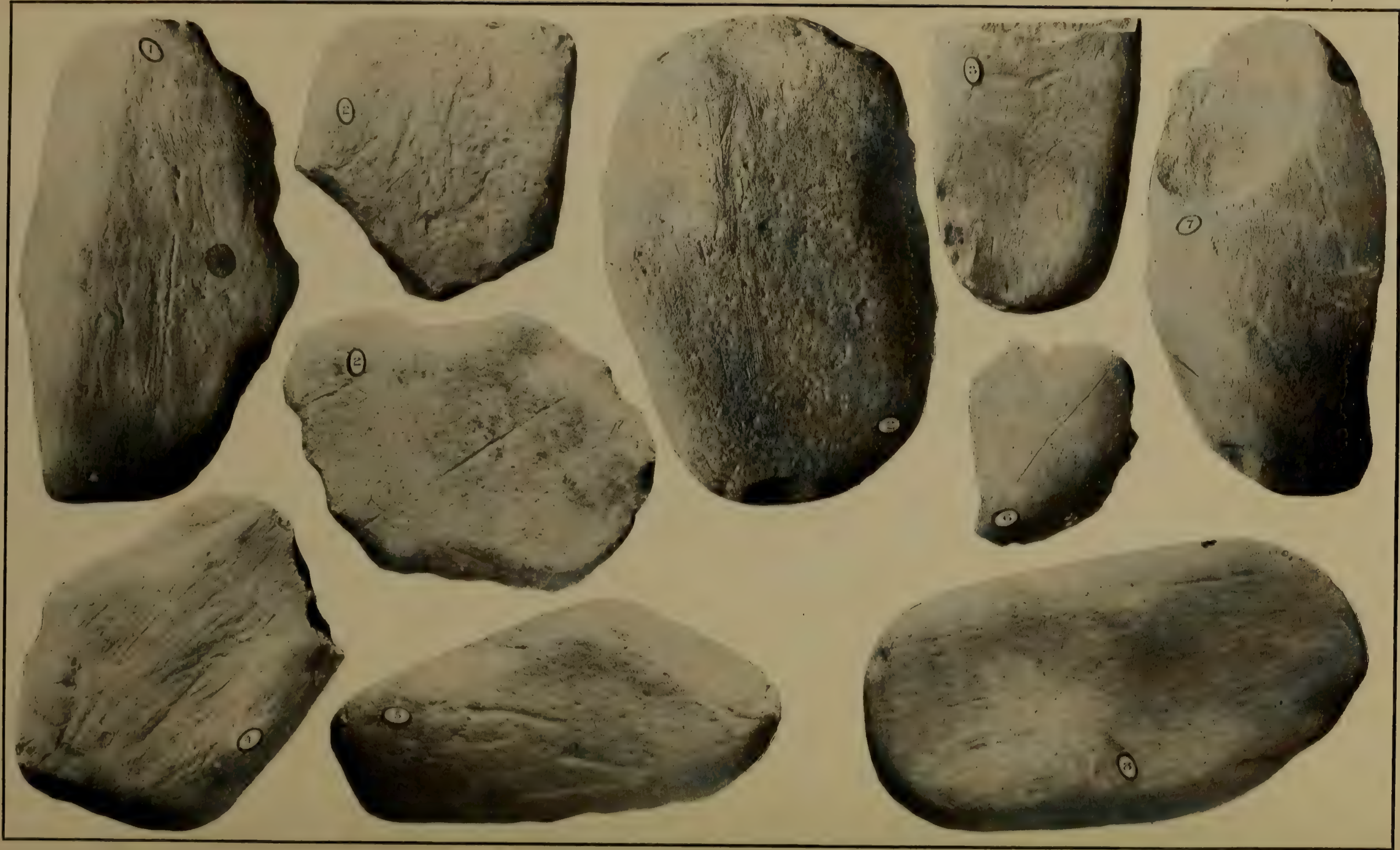
FIGURE 1.—*Map of Portions of southern Alberta and northern Montana*



GLACIATED PEBBLES FROM PRE-WISCONSIN DRIFT OF ROCKY MOUNTAIN GLACIERS ON REMNANTS OF THE BLACKFOOT PENEPLAIN, AND OF THE SECOND (LOWER) PLAIN IN SOUTHWESTERN ALBERTA AND BLACKFEET INDIAN RESERVATION, MONTANA

LOCATIONS.—A. Pebbles from the highest, or Blackfoot, peneplain. 1. Belly River Ridge, 5 miles north of Boundary. 2. Kennedy Ridge. 3. Ridge between Dry Fork and Livermore Creek, 5 miles southeast of Duck Lake. 4. Two Medicine Ridge north of the lower lake. 5. East slope of Saint Mary Ridge at head of Livermore Creek. B. Pebbles from second (lower) plain. 6. Ridge 3 miles southeast of Duck Lake. 7. Ridge north of Petersen Coulee. 8. Milk River Ridge 1 mile south of Horse Lake.

In September and October, 1912, the writers examined the deposits on most of the other remnants of the high-level plains in this region—that is, in the Blackfeet Indian Reservation east of Glacier Park—and made a reconnaissance trip in southern Alberta to examine the relations of the deposits described by Dawson and McConnell. In the course of this trip the writers crossed the boundary September 9 and moved by stages northward, camping a few days in each place, to Macleod, spent a day in the vicinity of Lethbridge, went westward up the valley of Oldman River to a few miles beyond the junction of the north and south forks of this stream, examined a portion of the southern part of Porcupine Hills, went southward from Pincher to Waterton lakes, and thence eastward around the foothills past Upper Belly River, and finally recrossed the International Boundary at Pike Lake west of Saint Mary River on October 3. While the opportunities afforded by such a trip so late in the season did not permit of exhaustive studies in any place, yet it afforded an excellent general view of the composition and relations of the several Pleistocene deposits and furnished a basis for interpretations presented in this paper.

DEPOSITS ON BELLY RIVER RIDGE

Between Belly River on the west and the heads of Lee Creek on the east a high ridge, which may be designated as Belly River Ridge (plate 13), extends northward to a point 5 or 6 miles across the boundary. At the abrupt north end this stands about 1,300 feet above Belly River, or about 5,750 feet above sealevel. This ridge is capped with about 100 feet of glacial drift, which is exposed in several places in scarps left by landslides on the underlying Cretaceous or Tertiary clays and shales. The drift is composed of angular to subangular (and some well rounded) pebbles and boulders up to 5 feet in length, representing the several kinds of rock from the mountains, embedded in a matrix of clay. Glacially scored stones are not abundant, but search resulted in finding numerous well striated pebbles of greenish argillite (plate 14, figure 1). In the upper part there are almost no pieces of limestone, though these are plentiful lower down. Evidently such have been removed by solution, and ledges of tillite outcropping 10 to 15 feet below the top of the section show the results of cementation by the calcium carbonate carried down by percolating waters.

The drift here is of the same character as that found in 1911, 8 to 10 miles farther south on this same ridge, west of Chief Mountain, at elevations of 6,000 to 6,300 feet above the sea, and also on Kennedy, Swift Current, Boulder, Saint Mary, and other ridges near the mountain front, with similar topographic relations, so that it is evident that there is here another remnant of the pre-Wisconsin glacial drift.

RIDGE EAST OF WATERTON LAKES

Looking west from the top of Belly River Ridge, there is a fine view of the north end of the Lewis Range, a few miles north of the International Boundary. From the horizon of the Lewis overthrust, at the base of the bold cliffs of pre-Cambrian limestone, a long low slope, developed on the soft Cretaceous and Tertiary rocks, extends several miles northward. Rising above this slope is a narrow wooded ridge, the straight though notched top of which is a remnant of the higher level on which the observer stands. West of this are Waterton lakes. This ridge was not examined, but it is thought probable that this also is capped with the pre-Wisconsin glacial drift.

ABSENCE OF PENEPLAIN REMNANTS IN SOUTHERN ALBERTA

As far as we traversed the plains of southern Alberta to the northwest and north, no other remnants of the high-level plains were seen. Even the Porcupine Hills, so far as seen, show nothing of such a high-plain surface. It is possible that some slight remnants of the peneplain persist close to the mountain front at places which we did not examine, but it is evident that Willis's Blackfoot peneplain surface has been almost entirely cut away from southern Alberta, unless it be represented by the top of Milk River Ridge, which, in the part north of the boundary, is farther east than the line of our traverse.

REMNANTS OF PENEPLAINS IN BROWNING AND BLACKFOOT QUADRANGLES, MONTANA

South of the 49th parallel, in the Browning quadrangle, the geology of which, especially, is being studied by Mr. Stebinger, and in the northwestern part of the Blackfoot quadrangle, there is the best preservation of remnants of the high-level plains found anywhere in the region. Over a triangular area having an extent of about 30 miles from north to south and about the same from east to west there are 15 or 20 more or less distinct remnants of the ancient plain surfaces having a total extent of 100 square miles. The nearly flat, plain surfaces of the bedrock underneath the surficial deposits on these elevated plateaus are planes of erosion developed indiscriminately over the flat-lying Cretaceous and Tertiary beds and over the upturned edges of the strata in the zone of folding and faulting which borders the mountain front. Taken together, they represent Willis's Blackfoot peneplain, the development of which he regarded as of early Tertiary age and one of the primary antecedents of the Lewis overthrust.[3] The question whether or not the peneplanation represented by these remnants of high-level plains occurred prior or subsequent to the time of the Lewis overthrust need not be considered in this connection. A noteworthy and fortunate circumstance is the remarkable preservation of these remnants in this part of the region.

Reason of Difference in topographic Development

The original extent of the Blackfoot plain to the northwest, north, and northeast is not known, but it may well be supposed to have extended to and over the site of the Porcupine Hills. Most of the region north of the 49th parallel is tributary to Saskatchewan River and Hudson Bay by way of Bow and Belly rivers and their tributaries. The distance to tidewater by way of these streams is much less than by way of Missouri River, whose tributaries drain the areas of the Browning and adjacent quadrangles. Though the streams were working in the same kinds of rocks, the area north of the boundary was thus the more rapidly denuded. Moreover, owing to this ascendancy, or to some other contributory cause, the waters from that part of the east slope of the mountains between the boundary and North Fork of Cutbank Creek were diverted northward via Saint Mary River to the Hudson Bay system, thus almost totally depriving the branches of Milk River of receiving any of the mountain waters. In consequence of this, while the adjacent region in southern Alberta was denuded of hundreds of feet of rock by vigorous streams heading in the mountains, totally obliterating the Blackfoot peneplain and developing in its stead a lower hilly surface, the comparatively feeble streams on the headwaters of Milk River cut only broad valleys 100 to 400 feet in depth, with tributary coulees dissecting, but not obliterating, the high-level plain.

So, also, farther south, where the tributaries of Cutbank Creek and Two Medicine River head in the mountain valleys and flow eastward across the adjacent plain to Missouri River by a more direct route than that followed by Milk River, the extent of denudation of the plain is more nearly comparable to that in southern Alberta, and no uneroded remnants of the peneplain are found until one reaches the divide between

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[3] Bailey Willis: Stratigraphy and structure of Lewis and Livingston ranges, Montana. Bull. Geol. Soc. Am., vol. 13, pp. 310, 336, 340.

Badger and Blacktail creeks, where again there is an area drained by streams which do not head in the mountains.

BLACKFOOT PENEPLAIN AND CYCLES OF EROSION

The remnants of the high plain and the deposits thereon in the Browning quadrangle and adjacent northwest part of the Blackfoot quadrangle are thus very significant in the interpretation of the physiographic and glacial geology of the region.

Calhoun[4] pointed out evidence of several cycles of erosion noted during the course of his observations in this area. Our interpretations are somewhat different in details, but much the same in general. The remnants of the high-level plains in the Browning and Blackfoot quadrangles instead of representing a single peneplain appear to represent two plains or sets of plains. The name "Blackfoot," proposed by Mr. Willis[5] for the peneplain, if it is to be applied to the initial physiographic features of this part of the plains, as he indicated, should be limited to the plain represented by the highest and oldest surfaces on these ridges. The locations and extent of these tracts are shown on plate 13. On Milk River Ridge this peneplain includes only the higher parts of the ridge immediately north of North Fork of Cutbank Creek and an isolated high plateau in township 35 north, range 11 west, 14 miles northeast of the head of the main part of the ridge. This head of the ridge is in township 33 north, range 13 west, and has an elevation of 5,900 feet above tide. From the flat top at this elevation a steep slope, apparently due to cutting down

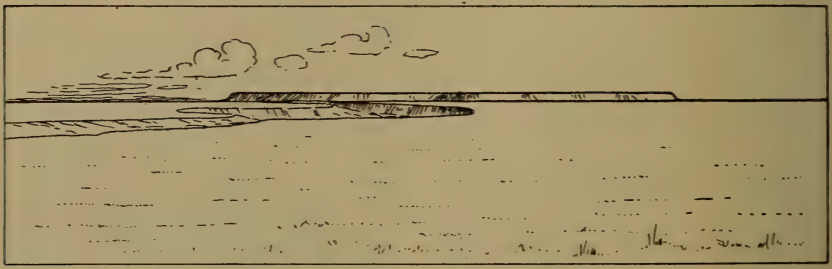

FIGURE 2.—*View northeastward from Browning-Babb Stage Road on the Crest of Milk River Ridge*

Showing the relations of the second peneplain (in foreground) to a remnant of the first or Blackfoot peneplain in background. (From photograph, partly diagrammatic in foreground.)

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[4] F. H. H. Calhoun: The Montana lobe of the Keewatin ice-sheet. Professional Paper No. 50, U. S. Geol. Survey, 1906, pp. 8 and 9.

[5] Bull. Geol. Soc. Am., vol. 13, p. 310.

from the higher level, declines northeastward 300 feet in a distance of 1½ miles. Beyond this for a distance of 19 miles the remarkably uniform, flat surface declines northeastward at an average rate of about 50 feet per mile. One traversing this gently sloping, second plain sees near the middle of the east boundary of the Browning quadrangle, in township 35 north, range 11 west, the remnant of the higher level standing with abrupt marginal slopes and flat top 100 feet or more above the second plain on which he stands. The relations are illustrated in figure 2. Small remnants of this upper level are also found on the highest parts of Horsethief Ridge and Landslide Butte, 15 to 19 miles farther east. Similar relations of a higher level and a second lower level are found on the ridge between the South Fork and Middle Fork of Milk River, and also on the ridge between Middle and North Forks of Milk River. The relations are such as to indicate that following the development of the highest plain, the Blackfoot peneplain, a moderate elevation of the region occurred during which this first plain was dissected. The elevation probably was not great and the stream gradients were low; so that broad, shallow valleys were eroded, developing the second set of smooth, flat, gently sloping plains. The directions of slope of the remnants of the highest plain are not in all places clearly toward present drainage lines. Those of the second set, however, are toward the present drainage lines, indicating that the main streams of the present system are following the lines of those of the second stage, but at relatively lower levels.

Following this stage of erosion renewed uplift caused dissection of the second set of plains and the development of the broad, open valleys, into the bottoms of which the present streams have incised their channels. The third set of smooth, gently sloping valley plains, those developed at this stage, are represented by the little dissected plain of the North Fork of Milk River, the more dissected valley slopes of Middle Fork, Livermore Creek, and South Fork of Milk River, the plain between Greasewood and Cutbank creeks and by Carlow Flat.

Wisconsin Stage of Glaciation and the third Set of Plains

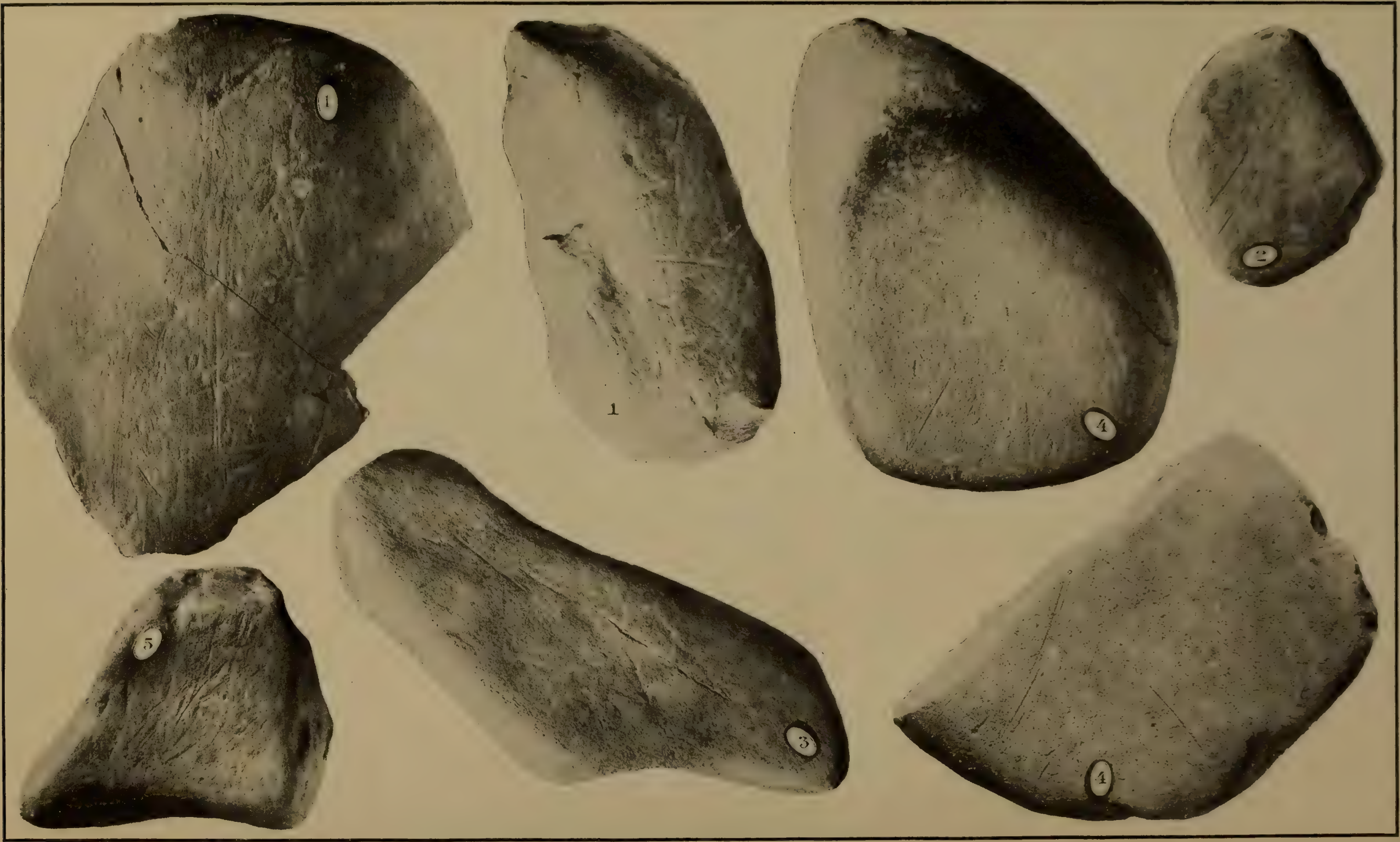
The development of the third set of plains was followed by the Wisconsin stage of glaciation. At this stage Saint Mary Glacier was diverted northward down the great open trough. In the vicinity of Duck and Goose lakes the ice overtopped Saint Mary Ridge and spread eastward onto the head of the North Fork plain. Cutbank Glacier extended down Cutbank Valley nearly 12 miles beyond the mountain front onto the plain between Greasewood and Cutbank creeks, and a small lobe occupying the spillway afforded by the sag in the crest of Milk River Ridge encroached on the plain in the head of the valley of South Fork of Milk River. The ice heading in the upper part of Two Medicine Valley, in Marias Pass, and in the valleys to the south united to form Two Medicine Glacier, spread eastward about 38 miles from the mountain front, and encroached on Carlow Flat. Waters from the melting of these glaciers and from the subsequent drainage of the area cut into these plains of the third set, eroding the inner valleys occupied by the present streams, some of which, notably that of North Fork of Milk River, are very sharp. The relations of the glaciers to these topographic features thus definitely determine that the third set of plains was developed prior to the last great extension of the mountain glaciers.

To the north of the Browning and Blackfoot quadrangles the dissection of the plains was carried so far at these several stages of erosion that no remnants of the higher levels have been recognized excepting those described on the east sides of Waterton lakes and Belly River Valley. To the south the only remnants of the higher plains noted are those seen by Mr. Stebinger between Birch and Badger creeks.

PRE-WISCONSIN DRIFT ON THE BLACKFOOT PENEPLAIN

Observations in 1911 and 1912 determined that the flat top of each of the high ridges near the mountain front was underlain by a deposit of glacial drift (plate 14, figures 2 and 4; plate 15, figure 5), in most places unmodified till, varying in thickness up to a maximum of about 250 feet on Saint Mary Ridge, which was clearly much older than the drift left by the mountain glaciers of the last great extension.

In this connection it may be noted that one of the finds of the past season was an excellent exposure of the drift on the east side of Saint Mary Ridge. In the woods on the north slope of the valley of one of the branches of Livermore Creek which cuts the east slope of the big ridge 6 miles due west of Horse Lake, in southeast 1/4, section 6, township 34 north, range 13 west, at an elevation between 5,700 and 5,800 feet above the sea, is a clean scarp due to slumping on the underlying Cretaceous shale. The scarp is about 75 yards long and has a maximum height of about 25 feet. At the west end a mass of the drift has crept out on the shale, leaving a rift 5 to 10 feet wide and 15 feet deep above the filling in the bottom. In the western half of the exposure the upper 10 to 12 feet consist of sand and gravel interstratified with glacial till; below this are 15 feet of coarse, bouldery till (plate 14, figure 5). Some of the finely striated boulders in this are 5 to 6 feet in length. The pebbles and



GLACIATED PEBBLES FROM PRE-WISCONSIN DRIFT OF ROCKY MOUNTAIN GLACIERS ON REMNANTS OF THE BLACKFOOT PENEPLAIN, BLACKFEET INDIAN RESERVATION, MONTANA,

LOCATIONS.—1. Hudson Bay Divide 3 to 4 miles north of Duck Lake. 2. Ridge 4 miles east of Duck Lake. 3. Ridge 9 miles southeast of Duck Lake. 4. Ridge 8 miles east of Horse Lake. 5. Cutbank Ridge.

boulders are exclusively from the mountain rocks, mostly quartzite and red and green argillite, with some of diorite and some from the limestones which Willis called the Siyeh and Altyn limestones. Many of the pebbles of the last mentioned, in the upper part of the section, are rotted to a loose, buff powder, as the result of solution. In places streaks of the stratified sand are cemented to hard sandstone, and below the upper 5 feet the till is cemented to a hard tillite by the calcium carbonate redeposited by the downward percolating waters.

Examination showed also that the flat top, on that part of the Hudson Bay divide between a point south of Spider Lake and the gap south of Galbraith's ranch, well above the marginal moraine of Saint Mary Glacier, is capped in the western part by 15 to 25 feet or more of glacial till, and farther east by thin, gravelly drift containing striated pebbles of greenish argillite (plate 15, figure 1). The superficial deposits on that part east of the gap south of Galbraith's ranch was not carefully examined. The top of the ridge where capped with this drift declines eastward in 5 miles from 5,300 feet above tide to 5,100 feet. The marginal moraine of Saint Mary Glacier, looping back to the northwest on the north side of Goose Lake (plate 13), crosses the highest part of the ridge at the west end, doubles sharply back to an east-northeasterly trend, and gradually descends the steep north slope of the ridge until it lies on the plain several hundred feet below the drift on the top of the divide (figure 3). It is thus clear that the latter deposit is not referable to the Wisconsin stage of glaciation. The elevation of the top of the ridge correlates it with that part of Saint Mary Ridge between Duck Lake and Divide Mountain as a remnant of the highest plain.

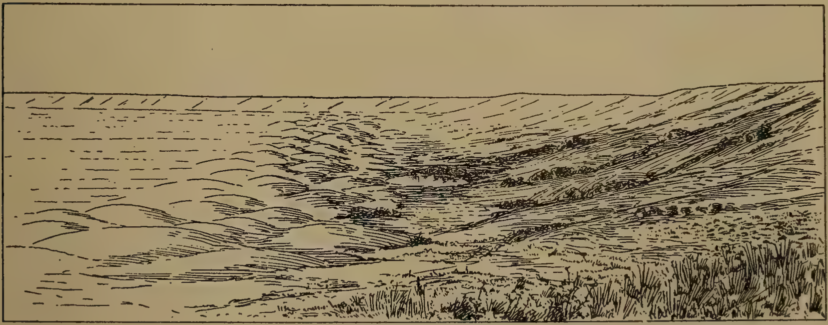


FIGURE 3.—*View looking Eastward from a Point about 4 Miles North of Duck Lake*

Showing relations of the terminal moraine of Saint Mary Glacier, of Wisconsin stage of glaciation, to the north slope of the Hudson Bay Divide, on whose top lies pre-Wisconsin glacial drift. (From photograph.)

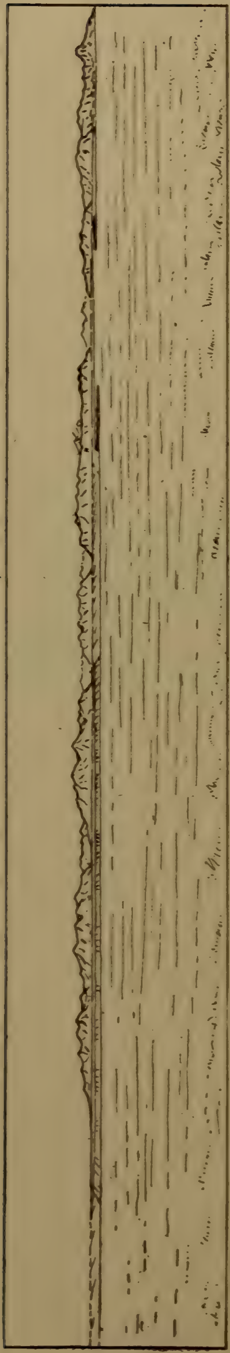


FIGURE 4.—*View looking Westward to Rocky Mountains across Remnants of the Highest or Blackfoot Peneplain from a Point 10 Miles East of Duck Lake*

The valley of Middle Fork of Milk River (in middle ground) is cut 400 to 500 feet below these remnants of the high-level plain. (From photograph)

Heading at a point 1 mile northeast of Davis Ranch and about 4 miles east of the east end of Duck Lake (plate 13), and extending thence northeastward a distance of 8 miles, is another abrupt ridge with remarkably smooth, flat top (figure 4). This high-level plain has a maximum width of about 1½ miles and is another remnant of the highest and oldest plain. In the northeastern part of township 36 north, range 11 west, the ridge has been lowered by erosion, but one going northeastward about 5 miles across the gap reaches the head of another like remnant of the highest plain, in northwest ¼, section 31, township 37 north, range 10 west, which extends thence northeastward nearly to the International Boundary. A small remnant of the same plain persists as the top of the ridge between the head of Kennedy Coulee on the north and South Fork of Milk River on the south.

These remnants of the highest plain are underlain by a deposit of gravel, mostly quartzite and red and green, siliceous argillite, with some diorites, all from the mountains. The tops and slopes of the ridges are grassed over, and it is only at intervals around the margins of the tops that as much as 1 to 3 feet of the deposit, which is probably thin, is exposed.

No striated pebbles were noted east of range 11 west, but in the western part of this township and at a point nearly north of Stones Ranch, township 36 north, range 12 west, section 23, careful search revealed some pebbles of greenish argillite with faint striations suggesting glaciation, but not indisputable. The pebbles at this place are subangular to well rounded and range in size from small pebbles to boulders 1½ feet in length. A brief but careful examination near the west end of the north slope, northeast of Davis Ranch, where the turf was broken by small scars due to slumping, revealed pebbles of greenish argillite clearly marked with finely graven striæ characteristic of glaciation (plate 15, figure 2).

On the ridge south of Dry Fork and Middle Fork of Milk River is the next remnant of this highest plain. That part west of the stage road, representing this highest level, is very narrow, most of the top of the ridge having been lowered to the second plain. On the slope at the west end, in northeast ¼, section 27, township 35 north, range 13 west, striated pebbles were plentiful, and also at the scarp, due to slumping in northeast ¼, section 13, of the same townships, where 3 feet of weathered gravelly drift is exposed (plate 14, figure 3). The deposit on the main highest part of the ridge, east of the stage road, was not examined, but on a small, isolated remnant of this highest plain, in section 12, township 35 north, range 12 west, gravelly drift was found containing well striated pebbles of greenish argillite (plate 15, figure 3). This drift-covered remnant of the highest plain is between 16 and 18 miles east of Flattop Mountain, and at the west end stands 65 to 75 feet higher than the top of the ridge to the west, which represents the second plain.

Going 4 miles farther in a direction somewhat south of east across the South Fork Valley, one reaches the most easterly remnant of the highest plain on which striated pebbles were found, that in township 35 north, range 11 west. This has a maximum width of about 1¼ miles and a length from north to south of 3½ miles. At points 3 miles apart glacially striated pebbles were found, although here as elsewhere only pebbles of greenish argillite have so far resisted surficial etching as to retain the striæ (plate 15, figure 4), and from a large part of these the finely graven scratches have been removed. The drift is coarse and gravelly, with pebbles ranging in size from fine to 1 foot in length and in shape from subangular to well rounded. The deposit is exposed in the upper part of the abrupt marginal slope, not in a clean, undisturbed section, so that it was not satisfactorily determined whether it constitutes a stratified, water-laid deposit, such as glacial outwash, or whether it is the coarse residuum of a deposit of unmodified glacial till.

TIME AND EXTENT OF THE FIRST MOUNTAIN GLACIATION

As has been indicated, unmodified glacial till occurs *in situ* on Belly River Ridge, nearly 10 miles north by west from Chief Mountain; on

Kennedy Ridge; on Hudson Bay Divide, about 10 miles east by north from Yellow Mountain; on Swift Current Ridge and Boulder Ridge; on Saint Mary Ridge; 4 to 6 miles east of the mountain front, on the highest parts of Milk River Ridge, as far as 6 miles out from the mountain front, and on the highest parts of Cutbank and Two Medicine ridges; so that it is evident that there was a pre-Wisconsin extension of the mountain glaciers well out beyond the mountain front. We are not, however, prepared to prove that the ice extended so far as the remnant of the highest plain in township 35 north, range 11 west—that is, 20 miles out on the plain—or that this extension occurred prior to the dissection of the highest plain surface, that of the Blackfoot peneplain.

It is unfortunate that the exposure of the drift on this isolated mesa (figure 2) is such that we were unable to determine whether it was water-laid, such as a deposit of glacio-fluvial outwash gravels, or whether it is the coarse residuum left *in situ* by the leaching and washing out of the finer material of the matrix of unmodified glacial till. If it is glacial outwash, it is evident that while the ice did not reach this far out on the plain, the glacial extension occurred prior to the dissection of this part of the highest or Blackfoot peneplain and the development of the next lower plain, which forms most of the top of Milk River Ridge. Gravels could not be washed from the lower plain up onto one which is 50 to 100 feet or more higher.

On the other hand, if this be regarded as the residuum of a deposit of unmodified glacial till, it appears that while the ice must have extended thus far—that is, 20 miles—from the mountain front in order to leave a deposit of till in this position, such a glacier might have spread out on the second plain already developed and have extended thence up over remnants of the older and higher plain. It may be stated, however, that the topographic relations of the highest drift-capped remnants to the remnants of the second plain are just such as would be expected if it were known that the earliest extension of the mountain glaciers occurred prior to the development of the second plain. The most significant remnants stand mesa-like (figure 2) above the levels of tracts of the second plain between them and the mountains. The abrupt marginal slopes facing the mountains have no drift banked against them leading down to the lower level. The only drift on the slopes is a sprinkling of pebbles let down by the recession of the slopes; the marginal slopes toward the mountains are eroded and not coated by drift deposits. Bordering coulees would hardly have been left unfilled with drift or have been excavated in such positions were there drift slopes leading up from the second to the highest plain.

Regardless of the exact mode of the deposition of the drift on these highest outliers, we think there is some ground for the opinion that the earliest glaciation occurred prior to the development of the second set of plains.

Deposits on Horsethief Ridge and Landslide Butte

The most easterly remnants of the highest plain known to the writers are found in the highest parts of Horsethief Ridge, southeast ¼, section 14, township 35 north, range 9 west, and Landslide Butte, township 36 north, range 8 west, distant about 35 and 40 miles respectively from the mountain front. Both these tops, on which are triangulation stations, are approximately 4,650 feet above tide water, or 350 feet lower than the mesa top just described. The highest part of Horsethief Ridge, which is a few square rods in extent, is capped with a deposit of coarse gravel similar to that on the high plains to the west. The pebbles, which range in size from a fraction of an inch to 1 foot in diameter, are composed exclusively of mountain rocks—pink, gray, and white quartzites, maroon and greenish argillite. In shape the pebbles are subangular, with more or less flat faces, edges largely smoothly rounded, but not very well rounded even among the smaller pebbles. No pebbles were found with glacially striated surfaces. The only difference in character between this and the deposit on the ridge 350 feet higher and 15 miles farther west is the apparent absence of striated pebbles on Horsethief Ridge. If they are parts of the same deposit, as seems probable, and if the deposit was made by outwash from glacial drift, it would be more surprising to find that pebbles rolled 15 miles or more by a stream had retained glacial striæ on their surfaces than to find them worn away. On the other hand, however, as was noted above, the pebbles are not particularly well rounded.

The deposit capping Landslide Butte is particularly well exposed at the west end in a clean scarp, the result of slumping on the Bearpaw shale. There is an undisturbed curved section 15 feet high and several hundred feet long besides the exposures in the faces of the masses which have slid down. Immediately beneath the black soil in part of the section is a deposit resembling till, consisting of gray clay having a maximum thickness of 3 feet and containing rather few pebbles. The main deposit consists of coarse gravel of the same lithologic composition as that on Horsethief Ridge and the high-level plains farther west, with the interstices between the stones filled with gray clay. In one part below this gravelly bed there is a larger percentage of the finer material constituting a clay matrix, in which the pebbles are irregularly embedded as in till. Here and there are streaks of sand.

The pebbles range in size from fine ones to boulders 1 foot in diameter, and in shape from subangular to rounded, and on the whole they are somewhat better rounded, as by water wear, than those on Horsethief Ridge, but are not well assorted as to size nor well bedded, though evidently water handled. The material as exposed resembles glacial morainal drift, but careful search by both of us failed to reveal a single pebble which was undoubtedly glacially striated, though faint markings on some of the pebbles suggested striæ.

Comparison with the Extension of Two Medicine Glacier of the Wisconsin Stage

The areal distribution of all the patches of high-level pre-Wisconsin glacial drift, excepting those on either side of Belly River, is on the plains directly opposite the catchment basins of Saint Mary, Cutbank, and Lake Creek glaciers of the Wisconsin stage, and this indicates that the ice which spread eastward onto the Blackfoot peneplain headed in these combined basins (plate 13). It appears, however, that either the bulk of the ice at the earlier stage must have been considerably greater than at the Wisconsin stage or that the topographic relations must have been markedly different from what they are now. Cutbank and Lake Creek glaciers at the Wisconsin stage were of comparatively small extent and extended directly eastward down unobstructed valleys. During the same stage the ice issuing from Kennedy Creek, Swift Current, Boulder, Saint Mary, and Red Eagle valleys, which combined to form Saint Mary Glacier, instead of extending northeastward onto the plain, was deflected northward down the Saint Mary Valley by the great ridge 1,000 to 1,600 feet high on the east. Farther south, Two Medicine Glacier at the same stage spread about 38 miles northeastward from the mountain front over an undulating plain.

The total area of the combined catchment basins of Saint Mary, Cutbank, and Lake Creek glaciers is approximately 310 square miles. The area of the catchment basin of the main part of Two Medicine Glacier (plate 13) is approximately 295 square miles—that is, excepting the basins at the heads of Whitetail and Birch creeks, which probably did not contribute largely to the main part of the Two Medicine piedmont glacier.

The average elevation of the divide forming the rim of the northern basin above sealevel is approximately 8,075 feet; that of the southern basin 7,525 feet.

The difference in elevation between the average height of the rim of the northern basin and that of the remnants of the highest plains, in which is the old drift, within 45 miles of the divide, is about 2,750 feet. In the area of the Two Medicine Glacier the difference between the average elevation of the rim of the catchment basin and the elevation of the undulating plain over which the piedmont glacier spread is about 3,400 feet.

From this comparison it is seen that while the areas of the two catchment basins are approximately the same, the difference in average elevations between the rims and the plains to be glaciated is about 650 feet greater in the case of the Two Medicine Glacier than in the case of the earlier northern glacier. From this it might be concluded that even if the tributary mountain gorges and the main trough of Saint Mary Valley had not then been excavated below the level of the crest of Saint Mary Ridge, so that that ridge did not then stand as an obstruction diverting the glacial flow from spreading freely northeastward onto the Blackfoot peneplain, yet no such piedmont extension of the ice as characterized Two Medicine Glacier at the Wisconsin stage would have occurred.

The southern catchment basin has not been wholly explored by the writers, but an inspection of the topography as delineated on the Marias Pass topographic sheet shows that on the whole there was much more obstruction to ready outflow of the ice from that basin than there would have been from the northern basin were Saint Mary Valley so much shallower that Saint Mary Ridge did not form a diverting dam.

The rise from lower Two Medicine Lake to the plain on the east is about 750 feet, yet the ice ascended this slope and spread eastward along the south side of Two Medicine Ridge to the gap traversed by the Great Northern Railway, and then deployed freely over the undulating plain about Browning. The outlet of Marias Pass east of Lubec is obstructed by transverse rock ridges 500 to 700 feet in height, and farther south, with the exception of Badger Creek Valley, there are no gorges opening directly northeastward from the divide, and even this valley is much constricted at the mountain front. The marvel is that a piedmont glacier heading in this catchment basin should have extended so far onto the plain as did Two Medicine Glacier. Considering all things, it appears that if the Saint Mary Valley were not so deep a diverting trough nor Saint Mary Ridge so high an obstructing dam, conditions would have been about as favorable for the extension of a pre-Wisconsin piedmont glacier onto the Blackfoot peneplain from the northern catchment basin as they were in the case of Two Medicine Glacier of the Wisconsin stage.

From this point in the discussion it is but a step to the assumption that the glaciation of the Blackfoot peneplain occurred at a time when Saint Mary Valley had not been cut down to so great a depth by some hundreds of feet, and that dissection of the plain to the east had not proceeded so far as the development of the second set of plains.

It is not necessary, however, to suppose that Saint Mary Valley was not cut at all below the level of the adjacent plain, nor that the Blackfoot peneplain was as yet relatively little dissected for any considerable distance to the north and south beyond the limits of the Browning quadrangle.

Let a generalized profile be drawn approximately along the line of axial flow through Marias Pass and out across the plain of Two Medicine Glacier (figure 5, number 2), and a like profile be drawn from the divide near Gunsight Pass, down Saint Mary Valley to the foot of the upper lake, and thence northeastward across Saint Mary Ridge and the remnants of Blackfoot peneplain (figure 5, number 1). Superposing one on the other, it appears that were Saint Mary Valley about 1,000 feet less deep than now, the obstruction interfering with the extension of ice directly northeastward from the northern catchment basin would not be greater than were the obstructions in the path of Two Medicine Glacier.

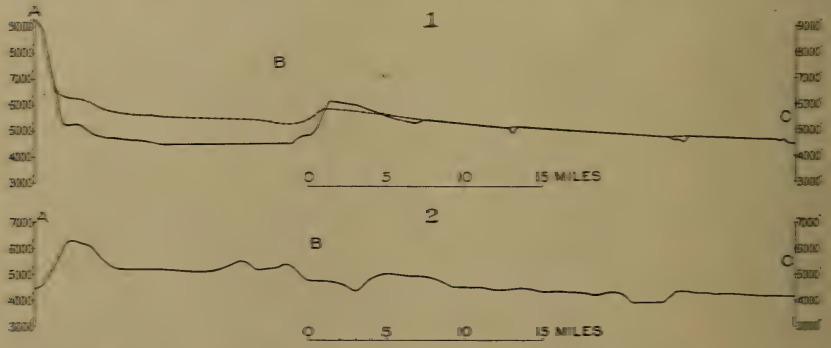


FIGURE 5.—*Profiles from Gunsight Pass and Bear Creek Valley*

Number 1.—Profile from a point near Gunsight Pass (A) down Saint Mary Valley to the foot of the upper lake, (B) and thence northeastward across Saint Mary Ridge and other drift-covered remnants of the Blackfoot peneplain.

Number 2.—Profile from upper part of Bear Creek Valley near Fielding (A), northeastward through Marias Pass and over the hills (B) east of Lubec, and thence across that part of the plain overridden by Two Medicine Glacier at the Wisconsin stage of glaciation.

Judging from the exposures seen in 1911 and 1912, the upper 250 feet or more of the highest part of Saint Mary Ridge is pre-Wisconsin glacial drift. This, of course, was not present at the time of the first extension of the ice. It might then be a reasonable assumption that the bottom of the valley at the foot of the upper lake lacked at least 800 feet of being as low as at present at the time of the glaciation of the Blackfoot peneplain. If this was the case, Saint Mary Valley for some distance farther north and also the other valleys heading in the mountains and those of the various tributaries of Milk River must have been correspondingly less deep at the same time and considerable remnants of the Blackfoot peneplain may have still persisted in southern Alberta, although probably much erosion would have been accomplished along most of the valleys and most of the intervening tracts would have been somewhat lowered and rendered uneven in consequence of the denudation.

DEDUCTIONS FROM RELATIONS OF PRE-WISCONSIN DRIFT OF THE KEEWATIN ICE-SHEET

If it were known that the recognized earliest advance of the continental ice-sheet into this region[6] was contemporaneous with the first extension of the Cordilleran ice, we would have something of a check on the relative antiquity of the oldest mountain drift in question. Calhoun has shown that there was probably approximate contemporaneity between the last great extension of the mountain glaciers and of the ice from the northeast, and with this conclusion we are in accord from our own observations, as described in a subsequent connection (page 557). We observed, as did Dawson and McConnell farther north, and as did Calhoun near the 49th parallel, that drift of the continental ice-sheet overlaps drift of the mountain glaciers. This relation and the fact that the Saskatchewan gravels, which Dawson and McConnell regarded as, in part at least, outwash from this mountain drift, extend eastward below the lower of the two northeastern drift sheets exposed in the region of Lethbridge, led these latter investigators to regard all the mountain drift east of the mountain front, including the moraines, as the oldest drift of southern Alberta.

Calhoun, however, pointed out, and with this again our observations agree, that there are in the sections observed no evidences that any considerable interval elapsed between the exposure of the mountain drift on the recession of the fronts of the mountain glaciers and the deposition of the overlapping drift by the continental ice-sheet, and he also stated that the lack of modification by erosion of the surface of the moraines corresponded as evidence of relative recency of deposition with that of the moraines of the late Wisconsin drift of the Mississippi Valley. Calhoun and we also were therefore led to the conclusion that drift of the mountain glaciers deposited in the valleys near and south of the International Boundary should be referred to the Wisconsin stage of glaciation, and that the same is true of the overlapping drift of the continental ice-sheet. We think this deduction applies also at least as far north as the valley of Oldman Creek, where the mountain drift is not confined to the valleys, but spreads over the intervening undulating areas, where erosion has left no remnants of the Blackfoot peneplain. This overlap was observed by us on South Fork of Oldman River west of Pincher, Alberta (township 7 north, range 21 west), and on Drywood Fork of Waterton River (township 4 north, range 30 west), and it was also observed by Calhoun and by us both on Belly River (township 2 north, range 28 west) west of Mountainview, Alberta, and on Saint Mary River near the International Boundary and some miles to the northward.

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[6] It should be stated that the interpretations of the present writers are based on what is now generally considered by geologists a well founded assumption that the upper and lower boulder clays, consisting of drift of the Keewatin Glacier, were deposited by extensions of the continental ice-sheet. Doctor Dawson seems not to have been ready to accept such an interpretation, for he states (Bull. Geol. Soc. Am., vol. 7, p. 61): "I have elsewhere given reasons for the belief that both these boulder clays of the western plains are attributable to the agency of floating ice (On the physiographical geology of the Rocky Mountain region in Canada. Trans. Roy. Soc. Can., vol. viii, sec. 4, p. 63 et seq.), but this need not here be specially insisted on."

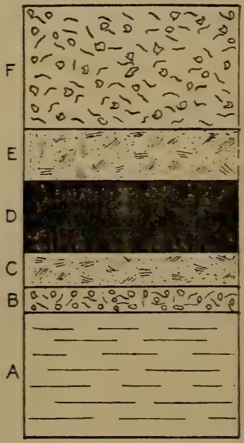

FIGURE 6.—*Section on Saint Mary River North of Sloans Ranch*

A, shale; B, northeastern drift, 2 feet, containing many decomposed boulders; C, typical loess, 5 feet, containing concretions, hard shells, and bones of small animals; D, soil, 10 feet, of black clayey loam, consisting of the weathered surface of the lower loess bed; E, loess, 6 feet in thickness, sandy at the top; F, northeastern till, containing crystalline boulders.

In the last two situations the two drifts are exposed near the levels of the present streams and at elevations of more than 1,000 feet lower than the nearest pre-Wisconsin drift-capped remnants of the Blackfoot peneplain but a few miles away. From this relation it is clear that the deposition of the imbricated drift in the valleys post-dated that of the drift on the high-level tracts by a long interval, during which the valleys were deepened hundreds of feet. It is to be expected on a *priori* ground that when climatic conditions were such as to cause the development of a vast *mer de glace*, extending from the Keewatin plateau to the Rocky Mountain front, considerable extensions of the mountain glaciers would also take place. Having then good evidence in the relations of the deposits themselves that such contemporaneous continental and mountain glaciation did occur at the Wisconsin stage, it is a rational inference that the deposition of the pre-Wisconsin mountain drift was approximately contemporaneous with that of the pre-Wisconsin continental drift which has been observed in the region.

If we judged from the topographic relations of the high-level drift to the valley drift in the Browning quadrangle, we might conclude at once that the interval of erosion between the formation of the two deposits was very long, and that the pre-Wisconsin drifts were correspondingly old.

This conclusion, however, requires some further qualification than that already deduced from the comparison of the relations of the high-level drift and that of Two Medicine Glacier presented above.

No pre-Wisconsin drift of the continental ice-sheet has been observed by the writers south of or near to the International Boundary.* Calhoun[7] observed drift outside the terminal moraine of the continental glacier farther south, which suggested an earlier stage of glaciation, but he found very little evidence which he thought supported the theory. On page 49, Professional Paper 50, he describes a section observed by him on Saint Mary River, north of Sloans Ranch, a few miles north of the boundary, and which he illustrated by a figure, reproduced here as figure 6. Of this Calhoun stated (loc. cit.):

> "This section furnishd the only discovered evidence of two distinct glacial epochs. As no other section was found showing like or similar phenomena, little stress is laid upon this."

It seems to the present writers, however, that this section merits some consideration because of its similarity to sections observed by them, and earlier by Dawson and McConnell, on Belly River in the vicinity of Lethbridge, Alberta, and because we have now clear evidence of an earlier extension of the mountain glaciers.

The writers examined numerous exposures on Saint Mary River both above and below Sloans Ranch, but this section, if still preserved, is evidently one of those which we did not examine. This section is particularly interesting because, if the lower bed of northeastern drift (B) is in reality unmodified pre-Wisconsin glacial till deposited *in situ* by the Keewatin ice-sheet, it means that Saint Mary Valley had at the time of that glacial extension been cut down approximately to its present depth, more than 1,000 feet below the level of the pre-Wisconsin mountain drift on Hudson Bay Divide, 8 or 10 miles to the southward, and more than

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* See statement at end of paper of a recent discovery of such a drift.

[7] Professional Paper No. 50, U. S. Geological Survey, p. 55.

1,600 feet lower than the drift capping Kennedy Ridge, a few miles farther southwest.

In response to a letter of inquiry concerning this bed (B) of northeastern drift, Doctor Calhoun writes in part as follows:[8]

> "Along this river, in the vicinity of Sloan Ranch, there had been a great deal of slumping and, with the time and help that I had at my command, I could not take the trouble to make any excavations. I was satisfied in my own mind that the lower bed B was really part of the older drift sheet, but, although I looked for many days, I found nothing else in any other river valley to substantiate this. The age of the boulders in the two sheets, as shown by the amount of weathering to which they had been subjected, was very different and, if I remember rightly, as far as I could make out from the badly weathered specimens, the rock material was also different. I left the section very much pleased with what I thought was evidence that could not be disputed as to the existence of two different ice-sheets from the northeast, but after many weeks of search I came to the conclusion that it would not do to claim the existence of another sheet upon the evidence of one section.
>
> "The layer B was a layer of boulders—some of them igneous and every one badly decomposed. In this layer there was not one sound rock of igneous origin, although there were quartzite gravels in the formation which were not decomposed. These decomposed igneous rocks occurred in considerable numbers. I am not sure whether this deposit was till or material let down by erosion. If it were till, it was very stony till. I found no other deposit in the area which contained badly decomposed igneous rock of undoubtedly northeastern origin."

From Doctor Calhoun's statement it seems to be not at all certain that the deposit is unmodified till left in its present position by the melting of the continental glacier. This being the case, the inference is warranted that it was let down by erosion from a higher level, perhaps from a horizon corresponding to the high tracts where the pre-Wisconsin mountain drift now occurs, and that its occurrence now at so low a level has no direct bearing on the amount of erosion accomplished and length of time elapsing since the deposition of the pre-Wisconsin drift.

It is not probable or, as it seems to us, possible, on account of the topographic relations, that the Keewatin ice was depositing the bed of drift (B) at so low a level in Saint Mary Valley in the vicinity of Sloans Ranch at approximately the same time that the mountain glaciers were depositing the drift on the high-level tracts.

Farther north, however, on Belly River near Lethbridge and on Oldman River as far west as Brocket (figure 1), there are considerable deposits of unmodified glacial till, a part of which evidently is and a part of which may be of pre-Wisconsin age, exposed in the bluffs, which are unquestionably *in situ,* not far above the present streams. Hence, even if we conclude that erosion of the Blackfoot peneplain had not progressed nearly so far as now in the Browning quadrangle and its immediate environs, we must concede that there is evidence 40 to 50 miles north of the boundary that the valleys of Oldman and Belly rivers had been cut to nearly as low levels as now before the pre-Wisconsin drift was deposited, and the intervening uplands must have been correspondingly lowered.

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[8] Personal communications, November 25 and November 30, 1912.

It may be well to present in some detail the results of our observations on the upper and lower boulder clays of the Keewatin ice-sheet.

In the course of our reconnaissance trip in southern Alberta a day was spent at Lethbridge and an examination was made of the series of drift deposits described by Dr. G. M. Dawson.[9] In the time spent, however, there was opportunity for study of only a small part of the fine exposures in this vicinity.

For some distance both north and south of the railway bridge at this place the drift deposits are well exposed in the bluffs forming the sides of the valleys. Belly River Valley at this place is about 300 feet in depth, a steep-sided trench cut in the undulating plain. Going down from the railway station into the valley south of the railway bridge to the vicinity of the municipal coal mine, filter beds, and electric powerhouse, the following series of deposits was observed in the east bluff:

Pleistocene Deposits on Belly River at Lethbridge, Alberta

		Feet
D.	Buff, loose-textured to moderately compact, clayey till of Keewatin Glacier (Wisconsin stage) containing plentiful Laurentian pebbles and Paleozoic (?) limestone pebbles, beneath upper grassed slope	150±
C.	Fine, gray, compact, cemented sand or silt (interglacial ?), with, in places, some intercalated thin layers of brown to black lignitic material; contorted in part in places; clay-iron nodules in places at top of bare shoulders of the bluff	10±
B.	Dense, compact, dark gray till of Keewatin Glacier (pre-Wisconsin stage), pebbles mostly from the Rocky Mountains; Laurentian pebbles plentiful but less abundant than in upper till; forms bold salient of the bluff	40 to 50
A.	Stratified gravel ("Saskatchewan," interglacial or preglacial), composed mostly of 4 to 6 inch, well-rounded pebbles of quartzites from the Rocky Mountains	10 to 12
	Cretaceous shale and coal	....

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[9] G. M. Dawson: Report on the region in the vicinity of the Bow and Belly rivers, Northwest Territory. Geological Survey of Canada, 1882-1884, 1884, pp. 139c-152c, and plate op. p. 140c.

G. M. Dawson (with collaboration of R. G. McConnell): Glacial deposits of southwestern Alberta in the vicinity of the Rocky Mountains. Bull. Geol. Soc. Am., vol. 7, 1895, pp. 39-41.

The bluff on the opposite side of the river at the bend north of the wagon bridge exposed the following (figure 7):

Pleistocene Deposits on Belly River near Lethbridge, Alberta

		Feet
D.	Loose buff till of Keewatin Glacier (Wisconsin stage), with Laurentian pebbles and pebbles from Rocky Mountains	3 to 13
C.	Laminated, papery silt	1 to 3
	Buff, wind-bedded loess, alternating with beds of fine, stratified sand (interglacial ?)	0 to 50±
B.	Compact, jointed till of Keewatin Glacier (pre-Wisconsin stage), with Laurentian pebbles and pebbles from Rocky Mountains. Upper 15 feet oxidized buff in places, dark gray below	25 to 30
A.	Quartzite gravels ("Saskatchewan," interglacial or preglacial), with some interbedded sand	10 to 15
	Cretaceous shale	100

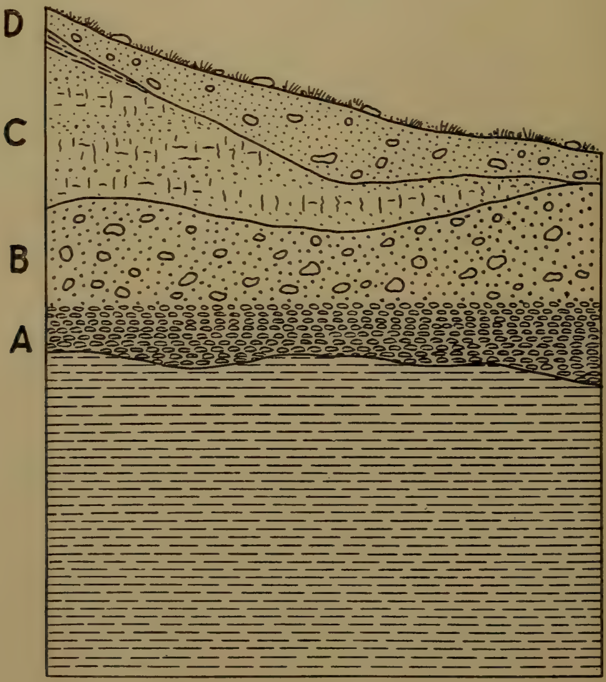

FIGURE 7.—*Section on Belly River near Lethbridge, Alberta*

A, quartzite gravels ("Saskatchewan"), interglacial or preglacial, 10 to 15 feet, overlying Cretaceous shale; B, pre-Wisconsin till of Keewatin Glacier, 25 to 30 feet; C, loess and wind-blown sand, 0 to 50 feet, overlain by laminated silt, 1 to 3 feet (interglacial?); D, Wisconsin till of Keewatin Glacier, 3 to 13 feet.

The gravel (A) in the two sections, which represents the Saskatchewan gravel of Dawson and McConnell, is composed exclusively, where examined, of water-worn pebbles from formations exposed in the mountains 60 miles to the west and southwest, mostly of pink and white quartzites, with smaller percentages of maroon and greenish argillite, diorite, amygdaloidal trap rock, gray limestone, and conglomerate containing black chert pebbles. At one point two or three granites were found among the loose pebbles in the excavation, but it was thought they might have rolled down from the drift higher in the slope which was deposited by the Keewatin Glacier. None such were found embedded in the stratified gravel. The top of the gravel is marked by a sharp horizontal line, and at only one point was any evidence of disturbance of the bedding, such as might be expected to result from their being overridden by the continental ice-sheet. Perhaps the gravel was cemented by ice to a solid conglomerate when such overriding took place.

By far the larger percentage of the pebbles in the dense compact lower till (B) is from the Rocky Mountains, probably derived by the glacier from deposits of gravel in the valleys such as those composing the underlying bed. Intermingled with these are granites and other crystalline rocks from the Laurentian formations west of Hudson Bay, showing that the till was deposited by the Keewatin ice-sheet. The surface of the lower till is uneven, especially in the second exposure described, and the oxidation of the upper part of this till is evidence of its exposure to weathering prior to the deposition of the upper till.

The stratified beds (C) indicate deposition during a stage of deglaciation. At the exposure north of the bridge there is nearly 50 feet of interbedded fine sand and loess-like silt resembling an eolian deposit. Overlying this is 1 to 3 feet of fine, laminated, papery silt. The relations indicate that this deposition was followed by a period of erosion, for the deposit thins abruptly toward the east side of the exposure until it pinches out entirely between the lower till (B) and the upper till (D). The upper till (D) mantles the slope and extends thence up to the upland as though it lay on the side of an interglacial valley. The extent of the interglacial deposit (C) northward down the valley was not determined. There seems to be considerable of the loess-like material on the east side north of the railway bridge, where such material exposed in the sides of a ravine is being used in making brick. South of the railway the bed (C) consists of partially cemented, laminated, grayish, fine sand or silt. A small opening in the grassy slope at one point in the side of a ravine back of the power-house exposed as part of these deposits the following:

Partial Section of interglacial Beds at Lethbridge, Alberta

	Inches
Sand, top not exposed.	
Soft, brownish vegetal material	0 to ½
Sand	4
Brownish vegetal material in thin layers	2
Sand	0 to 3
Black lignitic material, partly glistening coal	¼ to 1
Sand, bottom not exposed.	

The beds at this point were much contorted, either as the result of slumping or possibly from having been overridden by the later ice-sheet, so that it could not be determined that the vegetal material had actually grown where deposited. At one point, however, fine rootlike fibers were noted extending downward from one of the vegetal layers into the sand below. This vegetal material probably corresponds to the peaty or lignitic material observed by Dawson at this horizon several miles farther down the valley,[10] and represents one of the several phases of interglacial deposition in this region.

The upper till (D) is of looser texture and a higher percentage of the included pebbles are of Laurentian crystallines than in the lower till (B), although even here a considerable proportion of them are from the mountains.

About 40 rods below the confluence of Willow Creek and Oldman River, a few miles northeast of Macleod, the following section was observed:

Pleistocene Deposits on Oldman River near Macleod, Alberta

	Feet
D. Gray, sandy, unstratified loam	3 to 0
C. Buff to gray, loose till (Wisconsin ?) containing pebbles from the Rocky Mountains and a smaller percentage of Laurentian crystallines	15 to 20
B. Dark, fine, laminated silt (interglacial ?)	a few inches
A. Very dense, hard, gray till (pre-Wisconsin ?) containing pebbles from the Rocky Mountains and a somewhat smaller percentage of crystalline pebbles than in (C); overlies the eroded surface of the Willow Creek formation (Cretaceous or Tertiary) and fills two coulees eroded therein	20 to 30

It is thought that the deposits A and B in this section may correspond respectively to the deposits B and C in the sections at Lethbridge.

In none of the sections examined in this locality was the "Saskatchewan" gravel present, and in none other than the above was any evidence of more than one till observed. At some of the localities, however, the bottom of the drift filling the preglacial valley has not yet been reached by the stream.

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[10] Geological Survey of Canada, 1882-1884, p. 144*c*.

Going up the valley of Oldman River, a section wos observed at the wagon bridge near Brocket, 16 miles southwest of Macleod, exposing the following:

Pleistocene Deposits near Brocket, Alberta

		Feet
D.	Coarse gravel underlying a river terrace and lying on the eroded surface of the till	15
C.	Dense, dark, gray till (Wisconsin ?) pebbles, mostly from the Rocky Mountains with a small percentage of Laurentian crystalines	0 to 20
B.	Dark laminated silt (interglacial ?)	1 to 3
A.	Dense, gray till (pre-Wisconsin ?), not very stony, pebbles mostly from Rocky Mountains, with a very small percentage of Laurentian crystallines	30

Here again the deposits A and B may perhaps represent the beds B and C respectively in the Lethbridge exposure.

This is the most westerly point at which we observed any evidence of more than one sheet of till deposited by the continental glacier. At the nearest point the mountain front is distant about 20 miles to the southwestward. At the exposure near Brocket, the river has not yet cut down to the bottom of the drift filling in the preglacial valley. From this relation it appears that at least one of the main streams had cut below its present level before the first invasion of the region by the Keewatin ice-sheet of which we have evidence. Evidently preglacial erosion had progressed much farther here than it had in the Browning quadrangle, or else the lower till deposit of the Keewatin ice is not as old as that deposited by the Rocky Mountain glaciers on the Blackfoot peneplain in the Browning quadrangle.

In the vicinity of the confluence of Waterton and Belly rivers, and southwestward to points within a few miles of the village of Hill Spring, Alberta (township 4 north, range 27 west), numerous places were observed where the bottom of the drift filling has not yet been reached by the streams. In these places, however, no evidence was noted which seemed to warrant regarding the lowest till exposed as older than the Wisconsin stage. It can not therefore be asserted that these valleys were deeper than now this far south at the time the lower drift was being deposited in the vicinity of Lethbridge.

EXTENT OF THE UPPER AND LOWER DRIFT OF THE KEEWATIN ICE-SHEET

Regarding the relative extent of the upper and the lower till exposed at Lethbridge, Doctor Dawson makes this statement:[11]

> "As already mentioned, it is not certainly known how far the lower and upper boulder-clays of the plains or either of them extend to the west. Both are found at Lethbridge, 60 miles from the mountains, and if the line observed in sections on Highwood River corresponds with this division, both are there present to within about 15 miles of the base of the mountains and at an actual elevation of 3,700 feet. One or the other of these boulder-clays, however, extends westward along the Oldman River beyond the longitude of the Porcupine hills and at least as far west as Calgary, on Bow River, and there is some reason to believe that it is the upper boulder-clay which is thus most widely spread."

The uppermost glacial drift observed by the writers on Drywood Fork, in township 4 north, range 30 west, about 15 miles south of Pincher, Alberta, and but a few miles from the mountain front, is till containing pebbles of Laurentian granite and hence considered a deposit of the Keewatin ice-sheet. In this vicinity the surface is marked by sags and swells and many lakelets and marshy tracts, such as are characteristic only of morainal belts of the Wisconsin drift in the Missouri and Mississippi valleys. Similar topography characterizes the marginal belt of continental drift, thence southeastward to the International Boundary in the vicinity of Saint Mary River, and also in the drainage basins of Milk and Marias rivers.

In addition to the youthfulness of this morainal topography, the occurrence of the morainal drift within short distances of, but at levels hundreds of feet lower than, the pre-Wisconsin mountain drift on the remnants of the high-level plains near Belly and Saint Mary rivers shows unmistakably that the Keewatin ice-sheet which extended to the limit of continental glaciation in the region was that of a late stage, evidently the Wisconsin stage.

Without much more thorough examination than we have had the opportunity of making, we would not care to hazard an opinion as to the maximum extent of the earlier drift of the Keewatin ice in southern Alberta. The differences between the lower and the upper drift of the Keewatin Glacier where seen by us are not so marked as to enable us to be certain of the identification where only one was exposed. The lower part of much of the till seen in the bluffs along Belly River is very similar to the lower till at Lethbridge, even approximating its semi-indurated condition, yet the absence of any intervening non-glacial beds, or even a distinct line of separation between the looser upper part of the till and the denser lower part, renders one very hesitant to say that more than one stage of glaciation is represented. Where this is the case, it appears to us that the presumption is in favor of reference to deposition by the last ice-sheet traversing the area.

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[11] Op. cit., p. 60.

Relations of the earlier and later Drift of the Mountain Glaciers to that of the Keewatin Ice-sheet in southern Alberta

Doctor Dawson evidently did not think that the mountain glaciers extended beyond the front of the range at a time corresponding to the last continental glaciation in southern Alberta, for, in connection with his discussion of the conditions of deposition of the upper boulder clay which contains northeastern erratics, he states:[12]

> "That the glaciers which at the period of the Saskatchewan gravels protruded from the mountains must at this [later] time have shrunk back within the range, in the southern part of the district at least, is shown by the stranding of Laurentian boulders upon the old moraines of these glaciers close up to the foot of the mountains. It is possible that the Bow Valley Glacier may still have continued to hold some importance in the foothill region, but the abundant supply of well rounded gravels, with other circumstances, renders it probable that the Rocky Mountain glaciers generally had become strictly local and relatively insignificant."

We did not examine the drift of the mountain glaciers west of the limit of continental glaciation in the belt bordering the mountain front northwest of Belly River. From the relations which we observed in the vicinity of the latter stream, however, and farther south, we feel sure that there must have been a similar extension of the mountain glaciers farther north at the Wisconsin stage, and that it was in connection with this extension that the moraines bordering the mountain front were formed. We are inclined to disagree with the interpretation of Dawson when he states that he and McConnell "have found reason to assign to a very early period" the moraines close to the base of the mountains, which[13] are "evidently referable to glaciers of the Rocky Mountains."

Doctor Dawson states[14] that

> "Mr. McConnell had in 1890 carefully examined the sections of the glacial deposits along Bow River between the mountains and Gleichen (about 80 miles

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[12] G. M. Dawson: Bull. Geol. Soc. Am., vol. 7, pp. 62-63.

[13] Bull. Geol. Soc. Am., vol. 7, p. 65.

[14] Op. cit., pp. 38 and 39.

> eastward), and there found reason to believe that the Saskatchewan gravels of the plains represent and gradually pass into a 'western boulder-clay,' in approaching the mountains. This observation has remained unpublished, but now appears to be well established, and it follows from it, taken in connection with the facts already summarized, that there are no less than three distinct boulder-clays in the region here treated of, the oldest or 'western' boulder-clay being followed in time by that previously named the 'lower' boulder-clay, which is in turn distinctly separated from the 'upper' boulder-clay over a considerable part of the district, at least by interglacial deposits."

And again:[15]

> "As implied in Mr. McConnell's summary of the Bow River section, just given, it may, I believe, now be stated with certainty that the earliest sign of glacial conditions met with in southwestern Alberta is found in the evidence of the extension of glaciers from the Rocky Mountains to a certain distance beyond the base of that range. These may have reached nearly to Calgary, in Bow Valley, which has the largest drainage basin in the mountains, but were much less considerable farther south. A boulder-clay was at this early time laid down in connection with these glaciers, probably in part as a subglacial deposit, in part along their retreating fronts as a fluvio-glacial deposit. The latter as it is followed eastward gradually changes into the typical Saskatchewan gravels, in places associated with silty or sandy beds. All the drift material of this stage is either local or derived from the Rocky Mountain side, and it is probable that the boulder-clay of this time is actually connected with the mass of the moraine ridges and hills of Bow Valley and those found fringing the mountains in places farther to the south."

We agree with Dawson in the statement that "the earliest sign of glacial conditions met with in southwestern Alberta is found in the evidence of the extension of glaciers from the Rocky Mountains to a certain distance beyond the base of that range." We, however, find the best evidence of this is the drift on the remnants of the high-level plains in the vicinity of Belly River and in the Browning quadrangle. Evidently there are in the region at least four drift sheets instead of three, two deposited by the continental ice, of which the best evidence is found in the region of Lethbridge, and two deposited by mountain glaciers, of which the best evidence is found in the region south of that studied by Dawson and McConnell.

In Saint Mary River Valley, a short distance south of the boundary, and in Belly River Valley at a point west of Mountain View, about 10 miles north of the boundary, we found the drift of the mountain glaciers, whose surface is characterized by such youthful topography, extending down the valleys underneath the drift of the continental sheet. This relation was also observed and described by Calhoun.[16] Although he had not differentiated the earlier mountain drift, Calhoun concluded that there was no great difference in age between the drift of the mountain valley glaciers and the continental drift which overlapped it.

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[15] Op. cit., p. 59.

[16] Professional Paper No. 50, 1906, pp. 46-49.

The topographic relations in and near the Browning quadrangle show indisputably that the last great extension of the mountain glaciers occurred long after the deposition of the earlier mountain drift on the Blackfoot peneplain. Great valleys cut in this peneplain confined and directed the flow of the last ice-tongues projecting beyond the mountain front. Even with the checks noted above, which curb any tendency to refer all the dissection of the Blackfoot peneplain to time since the earliest mountain glaciation, yet it seems to us clear that the interval between the deposition of the high-level drift and the valley drift must have been very considerable. The moraines of the valley glaciers are very finely developed, showing in many places a sag-and-swell or kame-and-kettle topography, dotted with lakelets and wholly unmodified by erosion. These moraines are quite as well preserved as the famous "kettle moraine" of the Mississippi Valley, and we think can not be referred to deposition prior to the Wisconsin stage.

We did not differentiate any pre-Wisconsin mountain drift at any place excepting where it is preserved on the remnants of the high-level plains. In these places the areal and topographic relations are such as to render the differentiation unquestionable. Farther north, however, as we have indicated, the high-level tracts were probably largely cut away, even at the time of the early glaciation, and they have now wholly disappeared. This being the case, it is to be expected that with increasing distance northward from the boundary line the ratio of lowland to highland on which this early mountain drift was deposited must have gradually increased. All that part of southern Alberta from Oldman River southward to the boundary, excepting a narrow belt bordering the mountain front, is covered with drift from the Keewatin ice-sheet, and almost the only exposures of any considerable thickness of drift in this area are those afforded by the bluffs which form the steep sides of the narrow trench-like valleys cut by the streams in the undulating plain. It is thus to be expected that the evidence of an early mountain glaciation would be found, if at all, in this part of the region only in the valleys.

As stated above, we think that the drift of the mountain glaciers which we saw overlapped by drift of the Keewatin ice on Saint Mary and Belly rivers, within 10 miles of the boundary, must surely have been deposited by the valley glaciers of the last great extension. We do not know of any evidence clearly indicating that this drift is older. Calhoun cites[17] one section on Belly River within the terminal moraine of the Keewatin ice-sheet showing in order, beginning at the bottom:

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[17] Professional Paper No. 50, p. 49, fig. 31.

> "A Till formed by Belly River Glacier containing many boulders, all of which are smoothed and striated to an unusual degree, 75 feet; B, Soil, of which only a small exposure was seen, which contained no fossils; C, Till formed by the Keewatin ice-sheet, 80 feet."

He did not, however, regard the soil (B) as indicating any considerable lapse of time between the deposition of the mountain drift (A) and the overlying drift of the Keewatin ice-sheet (C). No such intervening bed as the soil (B) was observed by the present writers in any of the exposures where they saw mountain drift overlain by drift from the Keewatin ice.

RELATIONS OF THE "SASKATCHEWAN" GRAVEL

The relations of the "quartzite gravels" which have been included under the name "Saskatchewan" will now be considered.

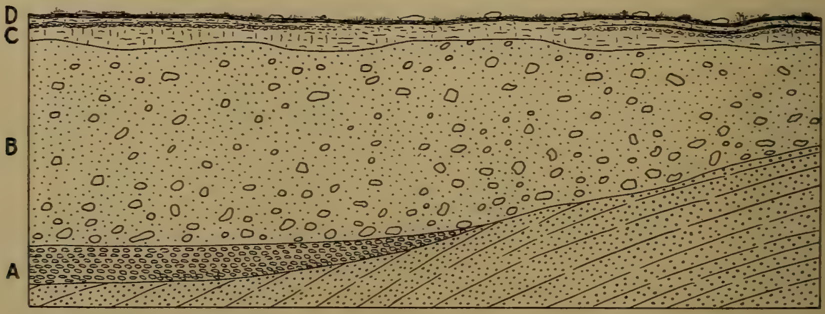
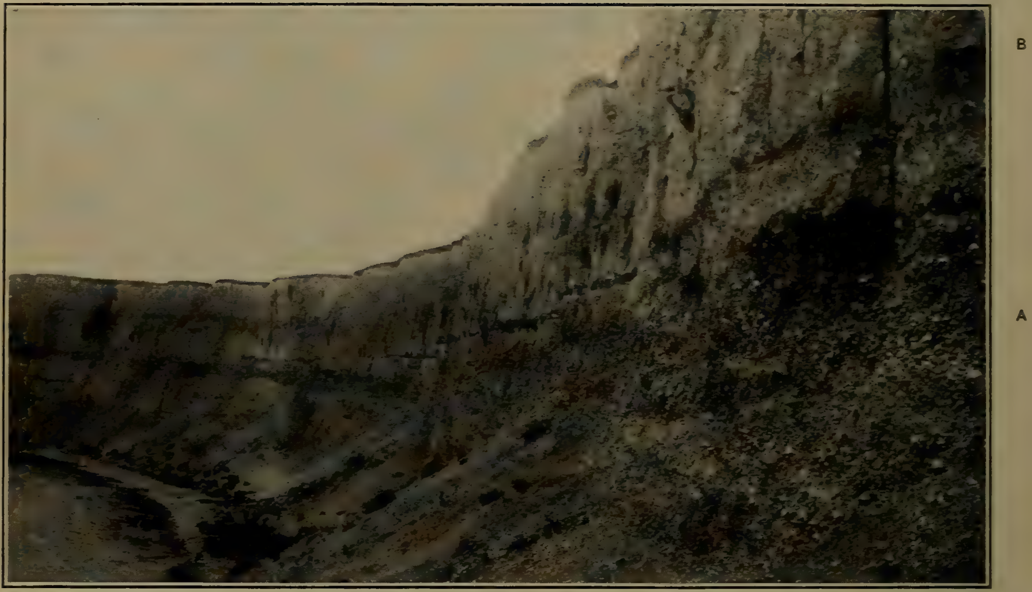


FIGURE 8.—*Section on Saint Mary River 1 Mile South of Kimball, Alberta*

A, quartzite gravel ("Saskatchewan"), interglacial (?), 0 to 15 feet, overlying sandstone; B, Wisconsin till of Keewatin glacier, 50 to 100 feet; C, loess-like clay, 10 feet; D, gravel overlain by a few feet of soil.

We observed on Belly River, in the vicinity of Lethbridge, 10 to 15 feet of "quartzite gravel" overlying the Cretaceous beds and underlying the lower boulder-clay (figure 7, A). Forty miles farther south in Saint Mary Valley, about 1 mile above Kimball (figure 8), 0 to 15 feet of similar quartzite gravel is overlain by 50 to 100 feet of till from the Keewatin ice-sheet, which apparently composes a single drift sheet and which we are inclined to regard as the upper boulder-clay. The bed of gravel pinches out midway in the length of this exposure against the rising surface of the underlying upturned and eroded sandstone, as though deposited only in the bottom of the preglacial valley.

At the bend nearly opposite Sloans Ranch, a few miles farther south,



DEPOSITS ON BELLY RIVER TWENTY-SEVEN MILES SOUTH OF MACLEOD, ALBERTA

A. Stratified, water-worn gravel (“Saskatchewan”) (preglacial or interglacial) pebbles quartzite, and other Rocky Mountain rocks, 15 feet. B. Till of Keewatin Glacier (Wisconsin stage), 10 to 12 feet. Pebbles mostly from Rocky Mountains, partly Laurentian crystallines. C. Laminated silt, 8 to 10 feet. D. Dark soil, 1 to 2 feet.

30 feet of coarse "quartzite gravel" lie on the eroded surface of the Cretaceous rocks and are overlain by 10 to 12 feet of till containing occasional Laurentian crystalline pebbles and itself overlain by a 5-foot bed of gravel containing Laurentian pebbles. The only evidence of mountain glaciation noted this far north in this valley was several 3-foot blocks of reddish argillite in a ravine between the last two points noted.[18]

Continuing southwestward upstream, another exposure shows 10 feet of "quartzite gravel" lying on the eroded surface of the Cretaceous sandstone and overlain by till containing Laurentian pebbles, and above this laminated, sandy clay containing a few pebbles from the Rocky Mountains and Laurentian crystallines.

At the boundary line the following section was observed:

Deposits on Saint Mary River at 49th Parallel north Latitude.

		Feet
C.	Gray clayey till of Keewatin Glacier, pebbles mostly from the Rocky Mountains, but with a small percentage of Laurentian crystallines (Wisconsin stage)	20±
B.	Gray till, pebbles so far as noted all from the Rocky Mountains (mountain drift, Wisconsin stage)	20±
A.	"Quartzite gravels" ("Saskatchewan," interglacial or preglacial) pebbles exclusively from the Rocky Mountains, well rounded, ranging in size from fine to 1½ feet in diameter	12 to 15
	Cretaceous rock.	

This is the most southerly point at which the writers have observed the "quartzite gravel" underlying either the drift of the Keewatin ice-sheet or the drift of Saint Mary Glacier.

At a point on upper Belly River and about 27 miles south of Macleod, in township 5 north, range 26 west, a fine exposure of the "quartzite gravel" was seen (plate 16).

Deposits on Belly River 27 Miles South of Macleod, Alberta

		Feet
D.	Dark soil	1 to 2
C.	Laminated gray silt	8 to 10
B.	Solid, buff ot gray, clayey till of the Keewatin ice-sheet, pebbles mostly from the Rocky Mountains, pebbles of Laurentian crystallines scattered throughout	10 to 12

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[18] At this intermediate point there is 15 to 20 feet of till, containing Laurentian pebbles overlying the eroded surface of the folded Tertiary (?) beds, and on the upturned edge of one of the harder beds glacial striæ were observed trending south 55° to 60° west. So also at the bend, nearly east of Sloans Ranch, at a point where overlain only by drift of Keewatin ice-sheet, the upturned edge of an oyster-bed was glacially smoothed and showed faint striæ trending south 30° to 50° west. These are the only points in the region traversed where we found glacial striæ on the Cretaceous or Tertiary rocks of the plains.

	Feet
A. Stratified, water-worn gravels ("Saskatchewan"), pebbles exclusively quartzite and other rocks from the Rocky Mountains, ranging in size from fine to 6 inches in diameter. Partially cemented, fine material fills the interstices and streaks of cross-bedded sand occur in places. The upper 1 foot of the gravels is oxidized to a dull orange tint, as though marking a zone of weathering. Bottom not exposed	15

At none of the sections examined farther up this stream were the gravels exposed. In fact, although the stream has cut 60 to 75 feet in drift below the level of the plain, at several places examined within a few miles of Hillspring village (township 4 north, range 27 west) it has not yet reached the bottom of the till of the Keewatin ice-sheet excepting at one place, where it swings against the side slope of the preglacial valley. Farther up the valley, where the stream cuts through the terminal moraine of the Keewatin Glacier and beyond this moraine, the stream frequently exposes the Cretaceous sandstones and shales underlying the drift, but nowhere are "quartzite gravels" present. Neither were the "quartzite gravels" found intercalated between the drift and the Cretaceous rocks at the exposures examined on Drywood Fork of Waterton River. No sections were examined on the Waterton excepting in the vicinity of its confluence with Belly River.

At most of the exposures examined on South Fork of Oldman River west of Pincher (townships 7 and 8 north, range 30 west) till rests directly on the Tertiary (?) sandstones or shales with no intervening "quartzite gravels." At the point between the South and Middle forks near their confluence 25 feet of loose buff till was exposed, a small percentage of the pebbles in which were Laurentian crystallines, overlying 35 feet of somewhat denser till, lighter buff in color and containing, so far as noted, only pebbles of rocks from the Rocky Mountains and beneath this sandstone. Looking back up the stream to an exposure which was not closely examined, it was seen that at that place 10 to 15 feet of stratified gravel intervenes between the lower bed of till and the Tertiary beds.

Dawson[19] describes three sections where similar gravel underlies the mountain till, one at a point on North Fork of Oldman, 2 miles north of its junction with Middle Fork; a second on South Fork of this stream, at a point about 12 miles from the mountains, and a third still nearer the mountains on Mill Creek. Concerning these he writes:

> "The two last-mentioned localities are within the limit of the country characterized by moraines, evidently due to local glaciers from the Rocky Mountains, and the indurated boulder-clay of the Mill Creek section is believed, like

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[19] Bull. Geol. Soc. Am., vol. 7, p. 43.

the moraines, to be a deposit of these glaciers. The lower gravels in this case and in that of Pincher Creek are obviously due to preglacial streams flowing from the mountains, and, although the name Saskatchewan gravels may be applied to them, they here evidently antedate the eastern gravelly representative of the Rocky Mountains or earliest boulder-clay. Further to the east, where this boulder-clay gradually passes into such gravels, there is no means of distinguishing between wholly preglacial beds and those which may have been formed during the main period of the Rocky Mountain glaciers. Many exposures of the Saskatchewan gravels may include both, and this without necessitating the supposition of any great chronologic break."

From the observations of Dawson and McConnell and from those of ourselves, it is clear that gravels exclusively from the Rocky Mountains, mostly quartzite, underlie the lower till of the Keewatin ice-sheet near Lethbridge, underlie the drift at a point on Belly River and at the confluence of North and Middle forks of Oldman River, where only one boulder-clay of the Keewatin ice-sheet, presumably the upper, is exposed, underlie mountain till at points where it is overlapped by drift of the Keewatin Glacier on Saint Mary River and on South Fork of Oldman River, and underlie mountain till beyond the limit of the drift of the Keewatin ice on South Fork of Oldman River and on Mill Creek. From these relations it might be concluded that the "quartzite gravel" is wholly a preglacial deposit.

As shown from quotations given, Dawson did regard the "quartzite gravel," where underlying mountain till, as preglacial, although he included it under the name "Saskatchewan." He states, however,[20] that from his studies on Bow River, McConnell "found reason to believe that the Saskatchewan gravels of the plains represent and gradually pass into a 'western boulder-clay' in approaching the mountains." Inasmuch as the gravels in the Lethbridge region underlie the lower boulder-clay of the Keewatin ice-sheet, he concluded that the mountain till was older than both deposits of the continental ice-sheet.

Our own studies in southern Alberta were not sufficiently exhaustive to warrant expressing an opinion as to the correctness of the theory that the same gravels which underlie the lower till of the Keewatin ice-sheet at Lethbridge grade westward into mountain till. It is quite possible that there is in places such a gradation, and that the mountain till into which such gravels grade, in valleys as far north as Bow River, or even on Oldman River, is really older than the lower boulder-clay of the Keewatin ice-sheet. We ourselves saw no ground for such a conclusion in the exposures which we examined. It is quite possible that this far north pre-

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[20] Bull. Geol. Soc. Am., vol. 7, pp. 38, 39; quoted on p. 556 of the present paper.

Wisconsin mountain till may have been deposited in valley bottoms, although in the Browning and adjacent quadrangles it is confined to the high-level tracts. We are inclined to think, however, that the mountain till which we found overlapped by till of the Keewatin ice on South Fork of Oldman River and on Drywood Fork of Waterton River is to be correlated with the moraines of the mountain glaciers farther west, and that it is of Wisconsin age. As has already been indicated, this certainly seems to be the case in the valleys of Belly and Saint Mary rivers near the 49th parallel.

The "quartzite gravels" in southern Alberta are largely concentrated along what appear to be pre-Wisconsin drainage lines. So far as we have seen them, these gravels are not exposed continuously for any considerable distance in the bluffs along the present courses of the streams, unless it be at Lethbridge, nor even in numerous consecutive, interrupted sections. It rather seems as though they are exposed only at places where the present streams have cut across older stream channels. Where the gravels appear in one section, neighboring sections above and below may show no such gravels, even where the stream has cut entirely through the drift deposits and into the underlying Cretaceous or Tertiary shales and sandstones.

On almost all those parts of the Browning and Blackfoot quadrangles which were overrun by neither the Keewatin ice-sheet nor the later mountain glaciers, and which have been degraded from the high levels of the Blackfoot and second peneplains, quartzite gravels are sprinkled on slopes and lowlands. The stones do not form thick deposits, but in many places are set almost closely enough to form a cobblestone pavement, and along the present stream courses they are concentrated to beds which are in places several feet in thickness.

It is clear from the relations that these quartzite pebbles and boulders have been let down during the process of degradation of the area from the high-level plains, where the evidence of pre-Wisconsin mountain glaciation is found. In their present positions, therefore, they are to be regarded as interglacial gravels, excepting where they have been rehandled and redeposited by the streams since the last extension of the mountain glaciers.

On the basis of these observations, we venture to express the opinion that part at least, if not all, of the so-called "Saskatchewan" gravel exposed at intervals along the valleys in southwestern Alberta are interglacial deposits derived by erosion from the pre-Wisconsin mountain drift, which, near the boundary line and to the south, was originally confined very largely to the high-level plains, but which farther north mantled the slopes and lower surfaces that had been reduced by degradation prior to the early advance of the mountain glaciers. The gravel underlying the lower boulder-clay of the Keewatin ice-sheet at Lethbridge may be preglacial. On the other hand, it may be that the pre-Wisconsin extension of the mountain ice preceded by a short interval the deposition of the lower boulder-clay by the continental glacier in the same way that the later mountain glaciers reached their greatest extension and began to retreat before the last Keewatin ice-sheet reached its farthest limit. If this was the case, then the gravels underlying the lower till at Lethbridge may be correlated with this pre-Wisconsin stage of mountain glaciation. Where quartzite gravel underlies the later mountain till, whether within or beyond the limit of extension of the last drift of the Keewatin ice-sheet, we are inclined to regard it as an interglacial deposit derived by erosion from earlier drift on the higher levels.

APPLICATION OF THE NAME "ALBERTAN"

The relations of the several glacial and interglacial deposits in this region being such as described above, question arises as to the application of the name "Albertan" proposed by Dawson.

Following the presentation of observed facts in the paper on the glacial deposits of southwestern Alberta,[21] Dawson presented some theoretical deductions, regarded as "the more obvious conclusions to be derived from these facts and their interrelation." In the course of the present paper reference has been made to some of the main conclusions which Dawson presented and some quotations from this summary have been given. The discussion of the conditions of deposition of the drift on the Porcupine Hills have not been considered in detail, and this need not be done in the present paper. Referring to the series of stages which Prof. T. C. Chamberlin had formulated[22] within the year immediately preceding the publication of the paper on the glacial deposits of southwestern Alberta, Dawson suggested what he regarded as "the probable relations of the glacial deposits of Alberta to this general classification."

It is not necessary to consider in this place all the particulars of the correlation proposed by Dawson. It should be stated, however, that he suggested the correlation of the lower boulder-clay exposed on Belly River with the "Kansan formation" of the Mississippi Valley. The name Kansan was at that time applied to the till-sheet underlying the Aftonian interglacial beds, and this sub-Aftonian till was regarded as the oldest known deposit of the Keewatin glacier.

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[21] Bull. Geol. Soc. Am., vol. 7, pp. 31-58.

[22] T. C. Chamberlin: The classification of American glacial deposits. Journal of Geology, vol. III, 1895, pp. 270-277.

James Geikie: The Great Ice Age, 3d ed., chap. xii, 1894.

Believing that the drift of the Cordilleran glaciers, which he had correlated with the gravels underlying the lower boulder-clay of the continental glacier, was older than this early till of the Keewatin ice-sheet and should have a distinct name, he proposed the name "Albertan" as follows:[23]

> "Reverting now, on the basis of the above correlation, to the Saskatchewan gravels and the 'western' boulder-clay, it will be apparent that these must represent an antecedent and unnamed stage of glaciation in North America. This, with scarcely any doubt, may, from the observations given in this paper, be regarded as that of the maximum of the Cordilleran glacier, and to it I would propose to apply the name of the Albertan stage or formation."

Further study of the Pleistocene deposits in the Mississippi Valley by the geologists of the Iowa Survey and by Mr. Frank Leverett led to the conclusion that it was the drift overlying rather than underlying the Aftonian interglacial beds which extended into northeastern Kansas and to which the name Kansan should be applied. After considering this question and making two excursions to examine some of the deposits, Professor Chamberlin discussed the matter of classification in an editorial in the Journal of Geology,[24] in the course of which he made the following statement:

> "During the past summer I have had the pleasure of making two excursions with Mr. Bain of the Iowa Survey to localities where the above formations are advantageously exhibited, and I have been impressed with the cogency of the arguments of the Iowa geologists. While, therefore, the case can not be said to be demonstrative, as yet, it seems best to accept the application of the nomenclature adopted by the Iowa Survey. This places the Aftonian beds below the Kansan series instead of above them. It puts the sub-Aftonian sheet of till in an earlier category, and, for the present, it may perhaps be regarded tentatively as Albertan, although, of course, it can not now be demonstrated to be equivalent to the Albertan beds of Canada."

The name "Albertan" thus passed into use tentatively as correlated with the sub-Aftonian of Chamberlin.[25] Such usage was continued until Calhoun concluded as a result of his observations that the drift of the mountain glaciers which is overlapped near the 49th parallel in the valleys of Saint Mary and Belly rivers by drift of the Keewatin Glacier was of Wisconsin age, and that the "quartzite gravels" on the high-level tracts in the region under discussion were pre-Glacial in age.[26]

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[23] Bull. Geol. Soc. Am., vol. 7, pp. 65-66.

[24] T. C. Chamberlin: Editorial, Journal of Geology, vol. 4, 1896, pp. 872-876.

[25] Frank Leverett: The Illinois glacial lobe. Monograph U. S. Geological Survey, vol. 38, 1899, p. 40.

Frank Leverett: Glacial formations and drainage features of the Erie and Ohio basins. Monograph U. S. Geological Survey, vol. 41, 1902, p. 20.

Following this the name "Albertan" has fallen into disuse by glacial geologists.[27]

It now appears from further study of the "quartzite gravel" and associated till deposits on the remnants of the high-level plains in the Glacier Park region that there is conclusive evidence, regardless of what may be thought of the deposits studied by Dawson and McConnell, that there was one or more earlier extensions of the Rocky Mountain glaciers. If, therefore, the name "Albertan" is to be used at all, it seems as though it should be applied to the drift on the remnants of the highest plain, the Blackfoot peneplain, as best preserved in the Browning, Montana, quadrangle. It should also include drift of the Cordilleran Glacier, which may be shown to be of the same age, though lying in valleys farther north, but should not include the mountain drift composing the moraines near the front of the Rockies in southwest Alberta, these latter moraines probably being of Wisconsin age. This makes the name a little incongruous because the most distinctive, and what should be regarded as the type, deposits of this drift have, so far as known, but very small areal extent in Alberta. There are, however, good exposures of a thickness of 100 feet of this high-level glacial till on the northern part of the ridge, which extends 5 or 6 miles north of the International Boundary on the east side of Belly River, and this may be regarded as typical of the "Albertan" in southern Alberta. A similar deposit may yet be found on the ridge east of Waterton lakes and possibly one or two ridges farther north, which were not overridden by the later ice, may carry some of this drift, although this is doubtful.

Thus applied it would be used in a sense not greatly different from that intended by Dawson as designating the stage at which occurred the earliest known extension of the Cordilleran Glacier and the deposits formed by this glacier at this early stage. Dawson used the expression "maximum of the Cordilleran Glacier," but it is not clear that the extension of the ice onto the plain in the Browning and neighboring areas at this earliest stage was on the whole greater than that at the Wisconsin stage. The deposits on the high levels extend farther out from the mountain front than do those of the Saint Mary and Cutbank glaciers, but not farther than those of the Two Medicine piedmont glacier.

On the whole, however, and after consultation with Dr. T. C. Chamberlin on the subject, we are inclined to think that continuance of the use of the name "Albertan" will lead only to confusion. We do not wish to propose any substitute at this time, preferring to designate this earliest known stage of Cordilleran glaciation as pre-Wisconsin until more extended detailed observations are made.

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[26] F. H. Calhoun: U. S. Geological Survey, Professional Paper 50, 1906, pp. 49-52.

[27] T. C. Chamberlin and R. D. Salisbury: Geology, vol. 3, 1906, p. 384.

The question of correlation with the deposits recognized in the Mississippi Valley must still be left open. It seems probable on *a priori* grounds that this early stage of glaciation in the Cordillera corresponded with either the earliest known stage of continental glaciation, that to which the names pre-Kansan, sub-Aftonian, and Nebraskan are now variously applied, or to the stage following the Aftonian interglacial stage to that now known as Kansan stage of glaciation. For better grounds of classification we must await detailed study of the pre-Wisconsin deposits in the area between this region and western Iowa.

A POSSIBLE INTERMEDIATE STAGE OF CORDILLERAN GLACIATION

On pages 534 and 535 attention is called to the presence of remnants of a second and lower plain, or set of plains, on the high levels of the Browning and Blackfoot quadrangles. The best representative of this second set of plains comprises the larger part of the top of Milk River Ridge. On pages 539 and 540 brief consideration is given to the hypothesis that the earliest extension of the mountain glaciers may have occurred after the second set of high-level plains had been developed, but the statement is made that we think there is some ground for the opinion that the earliest glaciation occurred prior to the development of the second set of plains. If this opinion is tenable, what is the significance of the glaciated material on the second set of plains?

For purposes of record we present here a somewhat detailed statement of the glacial deposits observed on the remnants of the second set of high plains.

In the former paper by the senior author[28] the following statement was made concerning the deposits on that part of the top of Milk River Ridge which was traversed in 1911:

> "Underlying this extensive high level plain is a yellowish to brownish oxidized gravelly deposit like that described above, consisting principally of quartzite with much green and red argillite, diorite, and some limestone. The stones are subangular to rounded, and it seemed to me there was no notable decrease in size with increasing distance from the mountains. Numerous boulders 1 to 1½ feet in diameter are found 2 to 3 miles from the head of this plain and 8 to 10 miles from the mountains, the source of all the material. That exposed in a ravine in the northeast quarter of section 12, township 33 north, range 13 west, consisted of clay, pebbles, and boulders mixed as in

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[28] Bull. Geol. Soc. Am., vol. 23, 1912, pp. 696.

glacial till. In the southeast quarter of this section 100 feet of unassorted material was found, and in the northwest quarter of section 6, township 33 north, range 12 west, a thickness of 150 feet was observed. Here and elsewhere glaciated pebbles were found, though these are nowhere abundant and consist mostly of the green, quartzitic argillite. Such striated erratics were found in the sides of the valley of Arnold Creek as far out on this plain as our traverse was extended."

In October, 1912, the top of this ridge was crossed and the drift examined at numerous places in township 34 north, range 12 west. In the east ½, section 32, is an old scarp exposing the drift, but partly grassed over and obscured, so that we could not determine positively that the deposit was unmodified till, though the heterogeneous mixture of fine and coarse material favors such interpretation. It is possible there was an error in location, and that this is the exposure seen by Mr. Thomas in 1911 and described above as in northwest ¼, section 6, township 33 north, range 12 west. At this exposure no limestone pebbles were seen and pebbles of diorite were disintegrating. Numerous striated pebbles of red and green argillite were noted. Such were also found at several other exposures (plate 14, number 8).

The new grade on the Browning-Babb stage road, which crosses the ridge in the northern part of this township, exposes 1 to 4 feet of gravelly drift. This is not definitely stratified and contains striated stones, but most of the pebbles are quite well rounded, as though water handled. Similar drift, with striated pebbles, was found on this second plain, extending northeastward through the northwest part of township 11 north, range 34 west, and also as far north as the northwest corner of section 16, township 35 north, range 11 west. This last location is nearly 20 miles from the mountain front. Striated pebbles were also found in the drift on the flat top of the hill west of the Wetzel Ranch, in sections 28 and 33, township 35 north, range 12 west.

On the ridge between Peterson Coulee and Livermore Creek many quartzite boulders 1 to 3 feet in diameter are to be seen where the stage road crosses. On the ridge north of Peterson Coulee (township 35 north, range 12 west, sections 9 and 11) finely striated pebbles were found in the gravelly drift at nearly every point where examination was made between the stage road and a point 2 miles east. Some of the pebbles are nearly as finely scored as those in the later drift (plate 14, number 7). No good sections of the deposit were seen.

Where slightly exposed in the north part of section 2, township 35 north, range 13 west, about a mile southwest of Goberts Ranch, 3 feet of oxidized, brownish gravelly drift was seen, containing striated pebbles.

Numerous striated pebbles were also found on the ridge north of Goberts Ranch, between the two stage roads, in sections 25, 35, and 36, township 36 north, range 13 west, and in west ½, section 30, township 36 north, range 12 west (plate 14, number 6).

Remnants of this second plain in the northwestern part of the Blackfoot quadrangle, in township 37 north and ranges 9 and 10 west, carry a similar gravelly material, evidently a continuation of the same deposits. These, however, were not examined with sufficient care to determine whether or not they contain striated pebbles.

The flat top of that part of Horsethief Ridge in township 35 north, range 8 west, is probably an isolated remnant of this second set of plains. This ridge, which is about 35 miles east of the mountain front, is capped with a gravelly deposit of the same character and composition as the ridges to the west. The pebbles here are almost wholly of quartzite, with but very little greenish argillite. They are mostly subangular, with more or less flat faces and with edges smoothly worn; but only a small part of them, even the smaller ones, are well rounded. No striated pebbles were found where the deposit was examined in the slight exposures at the crest of the west slope.

These observations show that the deposits on the second set of plains are quite as characteristically glacial, or glacio-fluval, drift as are those on the remnants of the highest set of plains at points equally distant from the mountains. The relations are not such, however, as to show clearly that these deposits represent a second and distinct stage of glaciation. As has been shown on pages 539 and 540, there are several possibilities:

A. The drift on the highest set of plains may have been deposited by a glacial extension prior to the development of the second set of plains. If the drift on the isolated higher tracts and in township 35 north, range 11 west, and in section 12, township 35 north, range 12 west, is a glacio-fluvial deposit, then its deposition and the first glaciation must have preceded the dissection of the peneplain. Depending on this interpretation are two hypotheses concerning the drift on the second set of plains:

(1) If this latter drift is in part at least unmodified glacial till, as we are inclined to think from the exposures seen on that part of Milk River Ridge south of Horse Lake, then we may regard it as evidence that at a second stage of glaciation the ice extended out onto the second set of plains.

(2) If this latter deposit be regarded as consisting wholly of modified drift, it may have been let down by erosional degradation of the deposits on the higher plain. In this case it is not evidence of a second stage of glaciation.

B. If the drift on the second plains be considered as partly unmodified till and partly the coarse residuum from the leaching of till, and if the drift on the isolated high tracts also be regarded as of the same kind, then it may be concluded that the first advance of the mountain ice occurred subsequent to the development of the second set of plains; that the ice deployed over these and extended thence up onto the higher tracts as far as 20 miles from the mountain front. Under these conditions we have evidence of but one pre-Wisconsin stage of glaciation.

More detailed work will be required to determine whether there was or was not a second pre-Wisconsin stage of glaciation.

SUMMARY

1. With the exception of one not yet examined, all the high ridges extending up to the mountain front are capped with pre-Wisconsin glacial till.

2. The Blackfoot peneplain is represented by the top of Belly River Ridge and that of the ridge east of Waterton lakes. These are the only remnants of the high-level plains seen in southern Alberta, unless the top of Dawson's Milk River Ridge is such. All others have suffered degradation.

3. There are finely preserved remnants of these high plains in the Browning and Blackfoot quadrangle south of the International Boundary.

4. The difference in topographic development between the areas north and south of the boundary is believed to be due to the ascendancy of Hudson Bay drainage over that of Missouri River.

5. The highest of the high-plain remnants represents the Blackfoot peneplain. Second and third lower sets represent later cycles of erosion.

6. The third set of plains was overrun by mountain glaciers of the Wisconsin stage.

7. Glaciated pebbles were found in the "quartzite gravels" on all the remnants of the highest plain examined within 20 miles of the mountain front.

8. There is ground for the opinion that at the time of the earliest extension of the mountain glaciers that part of the Blackfoot peneplain in the Browning quadrangle had been but little dissected, if at all, although farther north degradation had reached an advanced stage.

9. Gravelly material on Horsethief Ridge and Landslide Butte, 35 to 40 miles from the mountain front, is probably part of the same glacial or glacio-fluvial deposit, although no striated pebbles were found.

10. Comparison shows that when Saint Mary Valley was about 1,000 feet less deep than at present the conditions for extension of the com-

bined mountain glaciers onto the Blackfoot peneplain must have been quite as favorable as were those in the area of the Two Medicine Glacier at the Wisconsin stage. The latter piedmont glacier extended about 38 miles from the mountain front.

11. It is not certain that there is pre-Wisconsin drift of the Keewatin Glacier in any of the valleys within 30 or 40 miles north of the 49th parallel, so that it is not known that the streams had cut to anything like their present levels before the earlier glaciation. There is, however, unmodified glacial till in the valleys farther north which may be as old as the high-level mountain drift, showing that the streams had there cut down nearly to their present levels before the time of the earlier glaciation.

12. It is believed to be the uppermost drift of the Keewatin ice-sheet, that of the Wisconsin stage, which extends to the limit of continental glaciation in this area, and there overlaps till deposited by the mountain glaciers.

13. The mountain drift, which was seen to be overlapped by the drift of the Keewatin ice-sheet in the valleys of Saint Mary and Belly rivers and farther north, is characterized by uneroded moraines just beyond the limit of the drift of the Keewatin ice and is regarded as deposited at the same, Wisconsin, stage of glaciation. Dawson referred this drift and the moraines to his "Albertan" stage.

14. It is quite possible that there is pre-Wisconsin mountain drift in the valley of Oldman River or farther north, and that this grades eastward into "quartzite gravels," such as those underlying the lower boulder-clay of the Keewatin ice-sheet at Lethbridge. Dawson states that McConnell observed this relation farther north on Bow River, and from this relation he inferred the early deposition of the mountain drift. We did not, however, observe such a relation, and we feel quite safe in the correlation indicated above in paragraph 13.

15. We are inclined to think that a part at least, if not all, of the so-called "Saskatchewan" gravel exposed at intervals along the valleys in southwestern Alberta is an interglacial deposit derived by erosion from the pre-Wisconsin mountain drift, which, near the boundary line and to the south, was originally confined very largely to the high-level plains, but which farther north mantled the slopes and lower surfaces that had been reduced by degradation prior to the early advance of the mountain glaciers.

16. If the name "Albertan" is to be used, we think it should be applied to the pre-Wisconsin mountain drift on the remnants of the highest plain, the Blackfoot peneplain, as best preserved in the Browning, Montana,

quadrangle. It should also include drift of the Cordilleran Glacier, which may be shown to be of the same age, though lying in the valleys farther north, but should not include the mountain drift composing the moraines near the front of the Rocky Mountains in southwestern Alberta, the latter moraine probably being of Wisconsin age. Thus applied it would be used in a sense not greatly different from that intended by Dawson, as designating the stage at which occurred the earliest known extension of the Cordilleran Glacier and the deposits formed by this glacier at this early stage. We do not, however, favor the continued use of the name "Albertan."

17. It seems probable that the earliest stage of Cordilleran glaciation corresponds either to the earliest known stage of continental glaciation—that is, pre-Kansan or Nebraskan or to the Kansan stage—but the correlation is as yet undetermined.

18. The occurrence of gravelly deposits, underlying the second and lower set of plains and containing striated pebbles, may be regarded as evidence of a second pre-Wisconsin extension of the Cordilleran glaciers, but the relations are not conclusive.

ADDENDUM

Evidence of a pre-Wisconsin continental glaciation extending south of the International Boundary, and probably the counterpart of the piedmont glaciation on the high levels near the mountains, has recently been obtained as a result of field work during the summer and fall of 1913. About 15 miles east of the Sweetgrass Hills (see figure 1), on a small coulee tributary to Sage Creek from the north, in township 36 north, range 8 east, Montana, the following section was observed in good exposures extending several hundred feet along the nearly vertical banks of the coulee.

Pleistocene Deposits near Sage Creek, Township 36 North, Range 8 East, Montana

		Feet
C.	Stony, compact till of Keewatin Glacier (Wisconsin stage), containing an abundance of Laurentian crystalline pebbles and Paleozoic ? limestone pebbles. This till is as fresh and unweathered as that usually found in the drift of Wisconsin age	5
B.	Stony, compact, but much-weathered till of Keewatin Glacier (pre-Wisconsin stage), containing many Laurentian crystalline pebbles, but no, or only very few, limestone pebbles	6
A.	Clay and sandstone of Judith River formation (Cretaceous)	..

The recognition of two separate drift sheets in the above section rests entirely on the difference in the amount of weathering present in each, their general composition and appearance being almost identical except in this particular. In the older till the crystalline Laurentian pebbles present are so much decayed and friable that they fall to pieces with a light blow from the hammer, while in the upper till they are firm and fresh and practically unweathered. The limestone pebbles, which are fairly abundant in the upper till, are practically entirely leached out of the lower, which is partly indurated in places and deeply iron-stained. The difference in the appearance of these two bands of till is so marked that they can easily be distinguished at a distance of one-fourth to one-half mile. Judging from the amount of weathering present, it seems evident that the time interval between the lower and upper of these two tills is much greater than that between the upper (Wisconsin) till and the present.

On the whole, it seems reasonable to infer that the lower till here found corresponds to the lower till found on the Belly River at Lethbridge, Alberta, and also probably to the old continental drift found south and east of the margin of the Wisconsin drift in eastern Montana and western North Dakota.

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WATER AND VOLCANIC ACTIVITY

BY ARTHUR L. DAY AND E. S. SHEPHERD

(Read before the Society December 31, 1912)

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GREEN'S VIEW THAT THE KILAUEA EMANATION IS ANHYDROUS

In a book,[1] now little known and rare, William Lowthian Green, a distinguished Englishman, long in the service of the native government of the Hawaiian Islands, writes as follows:

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[1] Vestiges of the Molten Globe, part II, 1887, p. 82.

> "What we mainly wish to contend for and to impress upon geologists—for re-consideration, at least—is, that it may be a mistake to assert, as is so often done in the most positive manner, that water and steam are inseparably connected with volcanic action. On the contrary it would appear that elastic vapors have nothing to do with the liquidity of the Hawaiian basic lavas, and that as a matter of fact they do not seem to come up with them from below, whilst the basic minerals themselves give no indications in the main eruptions, of having been in contact with water, highly susceptible as they are, to such an influence."

Mr. Green was not only a keen observer of the manner of operation of the physical forces which participate in the volcanic activity to be seen in the Hawaiian Islands, but his opportunities for studying such phenomena were quite exceptional. His conclusion, supported as it was by many facts of observation, has therefore demanded, and indeed has received, consideration at the hands of geologists generally, although until very lately no one has been willing to consider it as having any application to volcanoes outside Hawaii.

Brun maintains the same View

More recently Albert Brun, a chemist of Geneva, Switzerland, has offered data[2] (apparently without knowing the work of Green) gathered from a great number of active volcanoes with intent to prove by analysis of the gases which he collected that water plays no part in volcanic activity. His words are as follows (page 249, following a detailed statement of reasons which will be considered below):

> "Il est donc *parfaitement certain que le volcan paroxysmal n'exhale pas d'eau. La preuve est faite.* Le grand *panache blanc* est composé de particules *solides* et *anhydres.*"
>
> "**Il faut donc que la théorie aqueuse disparaisse de la science.**"

(The italics and black-faced type are Brun's.)

Except for these two conspicuous instances, students of vulcanism have generally concluded[3] that water is usually if not always the chief agent in volcanic activity.

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[2] Recherches sur l'Exhalaison Volcanique. Geneva, 1911.

[3] G. Poulett Scrope: "Volcanoes," London, 1872. John W. Judd: "Volcanoes, What They Are and What They Teach," London, 1881. James D. Dana: "Characteristics of Volcanoes," New York, 1891. A. Geikie: "Textbook of Geology," vol. i, London, 1903. S. Arrhenius: "Lehrbuch der Cosmischen Physik," Leipzig, 1903. It should perhaps be added that some have expressed the opinion that the importance of water has been overestimated, without explicit denial of its participation in volcanic activity. (See, for example, J. G. Bornemann: "Ueber Schlakenkegel und Laven, ein Beitrag zur Lehre vom Vulkanismus," Jahrb. d. Kgl. pr. geol. Landesanstalt u. Bergakad, 1887, p. 230.)

It is not our purpose to discuss this question at this time except in so far as it may find application in the volcano Kilauea on the Island of Hawaii, but this volcano provided all of the material for Green's discussion and a very essential portion of that offered by Brun. It will therefore be of interest to record some observations made in the course of an extended study of this volcano by the writers during the summers of 1911 and 1912. The purpose of these studies is to obtain definite information about the character of the chemical reactions which take place in an active volcano, and in particular to determine the role played by the gaseous components, which are very important factors in both its chemical and physical activities. In many studies of volcanoes the gases have been allowed to escape entirely, while in others they were not captured until the nature of the components was so much altered by oxidation or otherwise that their identification, to say nothing of the determination of their relative proportions and the character of the equilibrium existing between them, has remained uncertain. On these broader questions, which are laboratory problems, most of the work still remains to be done. It is, however, quite possible to offer evidence on the participation of water and of some of the other volatile ingredients in the activity of Kilauea in advance of this study, which may require some years before all the questions which have been raised are satisfactorily elucidated.

DISCUSSION OF THE OBSERVATIONS OF GREEN AND BRUN

First let us review somewhat briefly the observations which led Green and Brun to the same novel conclusion, that water has no part in the volcanic activity of Kilauea. In the case of Green, such a review is not altogether easy. His reasoning is based on deductions from many phenomena, such as appeal to an observer on the ground: great lava streams without a trace of vapor rising from them; a condition of great activity in the lava pit of Halemaumau (the only portion of the Kilauea volcano now continuously active), with hardly a trace of any cloud above it; a rather conspicuous difference in character between the Halemaumau cloud (when there is one) and the clouds which arise from numerous steam cracks in the country round about, etcetera. Perhaps the chief factor which clinched his conclusion was the fact (which we also observed) that there are times when a magnificent cloud rises from the active basin, separated by but a day or two from periods when practically no cloud can be seen, and this with no apparent change either in the character or amount of activity visible in the basin. He therefore concluded that if steam was the moving force, and if the great white cloud was the manifestation of that fact, its presence must be expected on one day as much as on another in which the same gas and lava conditions appeared to prevail.

He was also able to discover no diminution in the liquidity of the lava, either in the crater or in the great lava streams during those periods when no cloud was seen, and therefore no causal connection between the presence of the gases and fluidity of the lava.

Had it occurred to Green to try to remelt some of the solidified lava after the gases had escaped, this last puzzling question would have been clearer to him, for the crudest effort would at once have revealed the fact, which since then has often been noted, that these lavas, when reheated to the temperature prevailing in the lava lake before solidification, remain quite rigid—the characteristic fluidity has departed with the escaping gases.

Brun's statement of his observations at Kilauea is more explicit. In particular he offers six definite reasons for believing that steam is not present either in the lava basin or in the cloud above it. They are these:

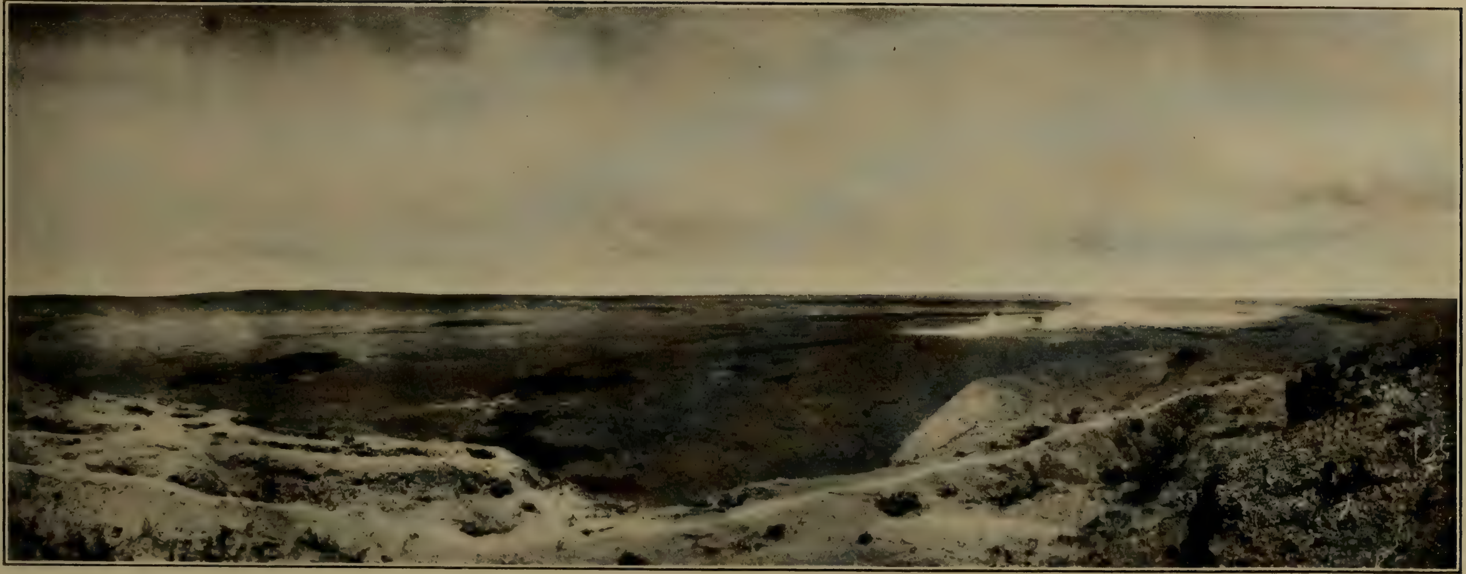
(1) The cloud arising from the crater does not evaporate in the sun as do the clouds arising from neighboring cracks after a rain, but can be seen floating majestically away often for 20 miles or more.

(2) No rainbow or other optical phenomena can be detected in the cloud arising from the crater, although rainbows are abundant enough in the vicinity under appropriate conditions.

(3) If the cloud were of steam emerging from white-hot lava, there should be an interval of a few feet between the point of emergence and the beginning of condensation (like the dark space immediately in front of the spout of a steaming tea-kettle) in which the steam should be invisible. No such dark space could be seen.

(4) As the cloud rises past the rim of the crater on the leeward side, the walls about the crater, being comparatively cold, should be wet with the condensed vapor, whereas in fact these walls remain quite dry.

(5) A train of glass tubes was lowered over the rim of the crater for a few yards on the side where the cloud was emerging, and through these tubes (some 250 feet distant from the nearest liquid lava, it may be remarked) air and the vapors carried by it were pumped for several minutes, but no trace of condensed moisture appeared on the inside walls of the tubes. Examination with a hand lens revealed the fact that the tube walls were quite thickly covered with crystallized salts, some of which were stated to be hydrates or to be hygroscopic, but this was deemed to be due to original moisture (!) carried on the tube wall before the beginning of the experiment. No analyses of the gases or of the solid salts are given.



A PANORAMIC VIEW OF THE KILAUEA CRATER FROM UWEKAHUNA (JULY 7, 1912)

Showing the present active pit of Halemaumau free from smoke. The small clouds rise not from the active pit itself, but from the cracks surrounding the pit (page 577) and are chiefly of steam

(6) A dew-point hygrometer carried along the rim through the smoke cloud showed a *lower* humidity within the cloud than in the clear air just outside of it.

Before proceeding to recount our own experience with these phenomena, it may be as well to express our belief that nearly all of these observations, both of Green and Brun, may be perfectly true as recounted above, and still offer no proof that the volcano exhales no water vapor.

THE EXPLANATION OF THE VOLCANO CLOUD

Green's observation that the great white cloud appears but intermittently may be explained by a somewhat closer observation of the conditions of formation of the cloud without assumptions of any kind about its possible water content. For example, we noted, during several months of constant observation, that the *visible cloud* does not rise directly from the surface of the liquid lava, but rather from cracks in the inclosing banks,[4] shattered, as they always are, by alternations of heat and cold as the liquid lava rises and falls in the basin. When the lava is high enough to completely flood the floor of the basin, these cracks are closed and all the gases emitted emerge directly from the surface of the lava into the atmosphere and have the temperature appropriate to the surface of the liquid (1,000 to 1,200° centigrade). At this temperature the gases (sulphur and hydrogen, for example) burn promptly on contact with the oxygen of the air and remain nearly or quite invisible. A thin blue haze can sometimes be distinguished above a bursting bubble[5] when conditions are exceptionally favorable, but this haze is so thin that spectators watching for it from the rim will generally disagree about its existence.

This is the condition of no cloud (plate 17) described by Green, and does not in the least suggest either a change in the composition or a diminution in the total quantity of the gases given off by the volcano.

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[4] Cf. plates 22, 23, 24, and 27.

Observations confirmatory of the conclusion that the smoke cloud when present does not rise from the liquid lava, but from the shattered floor and talus surrounding the basin, have been recorded by other writers.

For example, Prof. W. T. Brigham, Director of the Bishop Museum, Honolulu, who for fifty years has been one of the most careful observers of volcanic phenomena in the Island of Hawaii, writes as follows ("Volcanoes of Kilauea and Mauna Loa on the Island of Hawaii," Honolulu, 1909) :

Page 28 : ". . . It should be noticed how small the supply of steam in the active outpour of Kilauea really is."

Page 28 : "When the pit is empty of molten lava, the smoke is often most abundant."

Legend to plate 45 : "Lava pool below the rim of Halemaumau. . . . Little vapor rises from the portion which is active."

Legend to plate 50 : "There is little escape of steam from the lake surface."

William Lowthian Green ("Vestiges of the Molten Globe," vol. ii) writes (p. 170) : "Smoke, vapors, and gases seem to arise from the orifices of eruption and orifices in the neighborhood of molten lavas on Hawaii, and not from the lavas themselves."

[5] Cf. Frank A. Perret : "The Circulatory System in the Halemaumau Lava Lake during the Summer of 1911." Am. Jour. Sci. (4), vol. 35, 1913, p. 341.

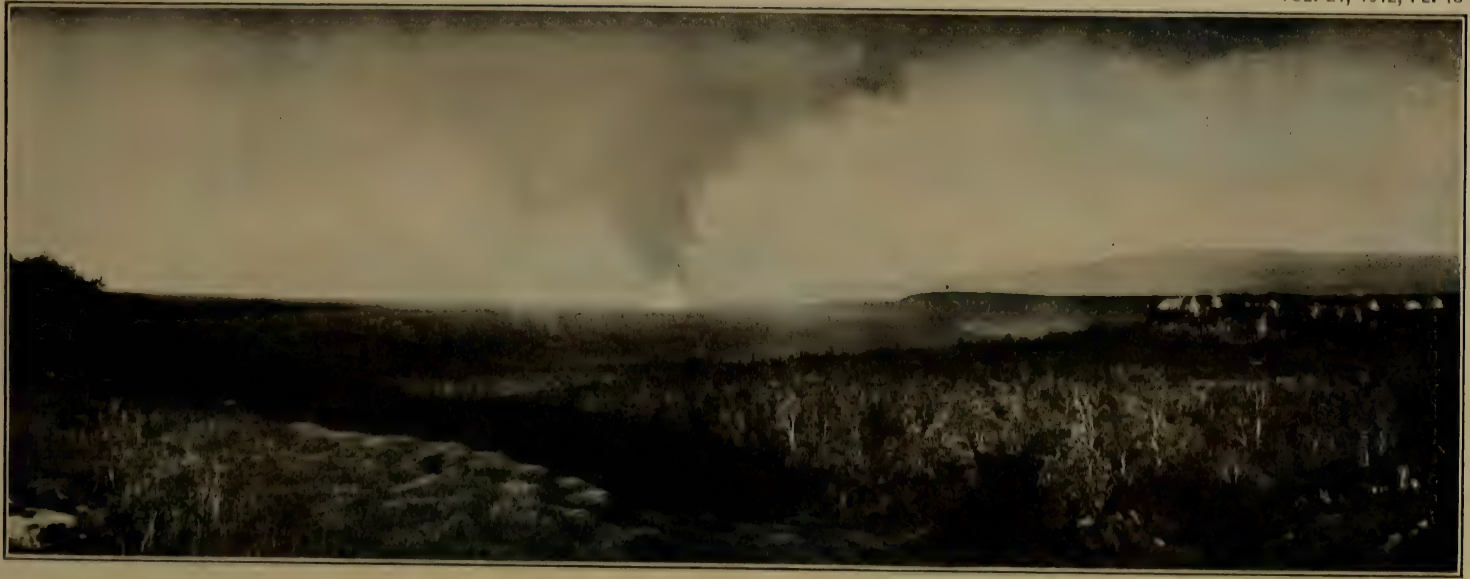
When the lava level in the lake has fallen 10 or 20 feet (which is an almost daily occurrence and often takes place within an hour), only part of the gases set free come from the free surface of the lava, and considerable quantities now appear through the shattered floor surrounding the basin. The gases bubbling out from the lava basin remain as transparent as before and for the same reasons, but the gases appearing from the cracks in the floor and from the surrounding talus are now cooled in passing through the cracks to such an extent that they no longer burn on reaching the oxygen of the air. Free sulphur is then set free in considerable quantities, unburned; this we were able to collect without trouble, both at the point of emergence and on the crater rim. It is this finely divided free sulphur which is mainly responsible for the beautiful white cloud (plate 18) above the crater and not crystalline chlorides, as supposed by Brun. In fact only a minute quantity of chlorine or its salts (less than 0.02 per cent) could be found in the emanations from the Kilauea basin during the period of our visit.

Our observation of the appearance and behavior of this cloud is therefore in full accord with the observations of both Green and Brun, so far as recorded, but there is nothing in the facts thus established to show whether the sulphur is accompanied by water vapor or not.

Herein is also to be found a sufficient explanation of Brun's observations—(1), (2), and (3), page 576—that the cloud when present does not evaporate after leaving the crater, that it gives no optical phenomena in sunlight, and that it is immediately visible as it emerges from the floor cracks and talus without a transparent zone separating the point of emergence from the visible cloud—results which would be expected if the cloud consisted only of steam, but not if it contains much sulphur.

BRUN'S HYGROMETRIC OBSERVATIONS

The remainder of Brun's observations of the apparent absence of water vapor may find appropriate explanation in the fact that they were made in an unsaturated atmosphere (as shown by his elaborate records of the hygroscopic state of the air during his observations) at a distance of more than 250 feet from the point of emergence of the gases, and the further fact that the cloud not only carries sulphur, but two of its oxidation products, SO_2 and SO_3, both of which in these circumstances are effective drying agents. It may very well happen that water is given off in considerable amount by the volcano and yet remains invisible; for, in addi-



PANORAMIC VIEW OF KILAUEA CRATER FROM THE VOLCANO HOUSE (JULY 31, 1912)

Showing the beautiful smoke cloud. Mauna Loa is seen in the distance at the right tion to the portion disappearing as vapor in the unsaturated atmosphere,[6] a considerable additional quantity will condense about the finely divided sulphur particles, serving as nuclei of condensation.

Furthermore, in our opinion, Brun's explanation of what he deemed to be crystals of hydrated salts in his vacuum tubes and in the pipe line through which his gases were pumped is a somewhat fortuitous one, and certainly leaves an element of reasonable doubt whether their presence was entirely due to moisture carried by the tubes thmselves. The very care exercised by Brun would seem to make this unlikely except for the fact that it was offered by Brun himself. If it could be shown that these hydrous salts were regular inhabitants of the sulphur cloud, the comparative dryness of the cloud would also find ready explanation.

Brun's final contention (section 6, p. 577) that a dew-point hygrometer carried along the rim of the crater shows a lower humidity within the cloud than in the clear air immediately outside of it appears to be open to serious criticism from the physical side, although if one may judge by the space given to these observations in "L'Exhalaison Volcanique," this is the point which Brun himself regarded as the most convincing observation of all. It appears to be a matter of grave doubt whether the readings of a dew-point hygrometer in an atmosphere containing SO_2 and SO_3 have any significance whatsoever, in view of the well known affinity of these compounds for water. The cloud could hardly be charged with better drying agents than these under the conditions described; it might, therefore, *a priori,* be expected to contain less free moisture than the adjacent atmosphere which does not contain these drying agents. Furthermore, the effect on the dew-point apparatus itself of exposure to the cloud containing SO_2 and SO_3 may be a factor of considerable significance. The first reading of the instrument might well be approximately correct, but subsequent readings would surely all be subject to the effect of uncertain amounts of SO_2 and SO_3 carried by the instrument in consequence of the first exposure. This would have the effect of rendering all the subsequent readings of the series quite valueless as a measure of the water content either of the air or of the cloud.

In order to support the view that the atmosphere within the cloud containing SO_2 and SO_3 is necessarily drier than air which does not contain these substances, several measurements of dew-points were made by us in an appropriate laboratory apparatus, of which the results will be found in the table below. The first column contains the dew-point of air at varying degrees of saturation; the second column the dew-point of the *same air* to which 1 per cent of SO_2 (air + 1 per cent SO_2 is still respirable) has been added. All observations are in duplicate.

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[6] Prof. J. P. Iddings, Prof. H. D. Gibbs, of the University of Manila, and several chemists from the Philippine Bureau of Science have observed gaseous emanations rising in great volume near the volcano Taal, which were found to contain large quantities of water and yet gave no trace of a cloud. (Unpublished records of the Bureau of Science, Manila, P. I.)

Observations of Dew-points

Air of random water content	The same air + 1 per cent SO_2	Difference
7.2°	6.4°	—0.8°
7.0	5.8	—1.2
19.2	18.1	—1.1
19.4	18.4	—0.9
20.4	17.5	—2.9
20.2	18.5	—1.7
21.6	19.7	—1.9
21.1	19.4	—1.7
21.5	19.0	—2.5
21.5	20.4	—1.1

Dew-point observations in the nature of the case can make no pretensions to high accuracy, but the effect of charging the air with a very small quantity of SO_2 is shown most convincingly. The effect of the addition of SO_3 would have been still greater than that of SO_2, since it forms H_2SO_4, a notable dehydrating agent; but this effect is somewhat more difficult to examine experimentally and so was not undertaken; indeed, it was unnecessary, in view of the fact that the point at issue is abundantly proved by the observations contained in the table above. Brun has therefore proved no more with his hygrometer measurements than that the great white cloud does not consist entirely of water vapor, but it is not possible to estimate the percentage of water contained in it from any figures based on dew-point determinations under the conditions which he describes.

From this evidence it appears clear that the observations of fact noted by both Green and Brun may for the most part be precisely as described, and still the conclusion that water is not exhaled by the volcano Kilauea remain in doubt.[7]

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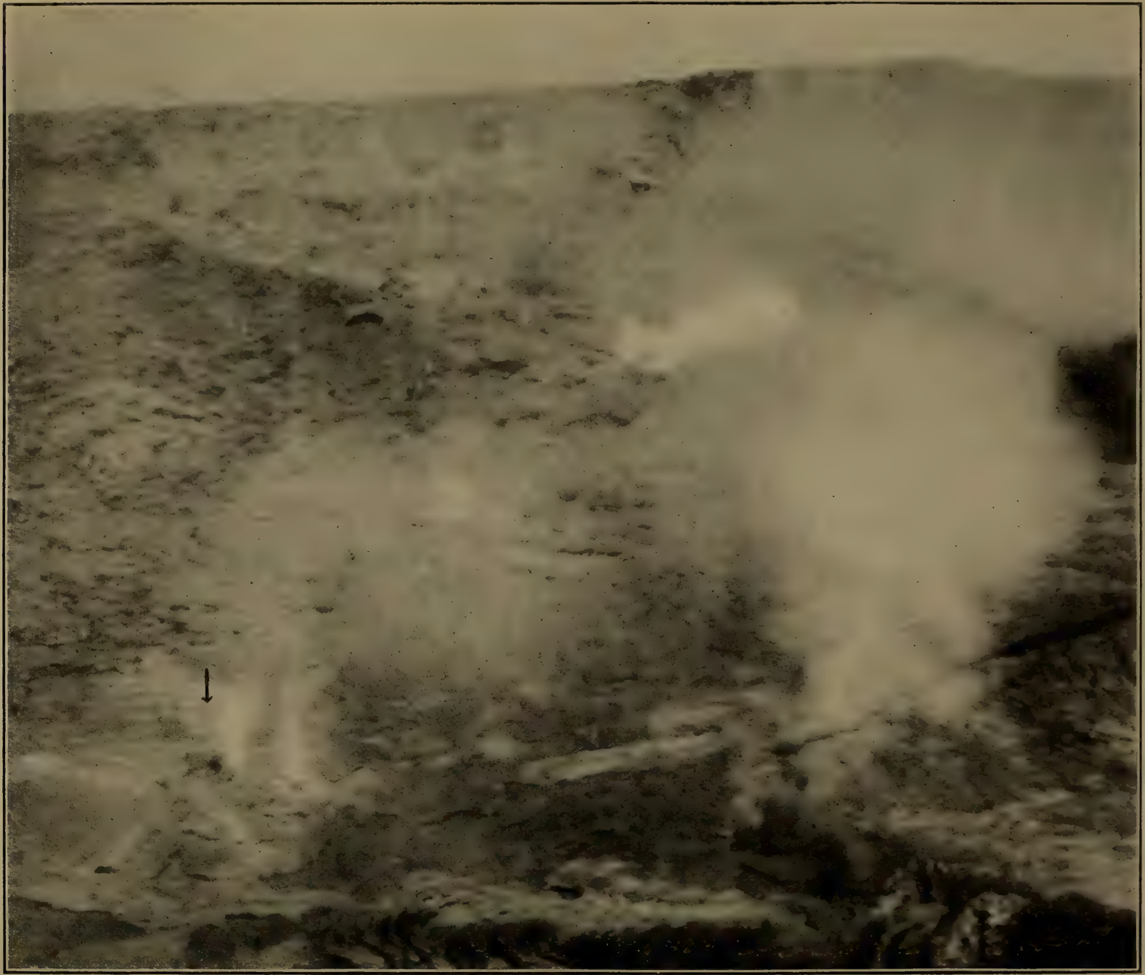
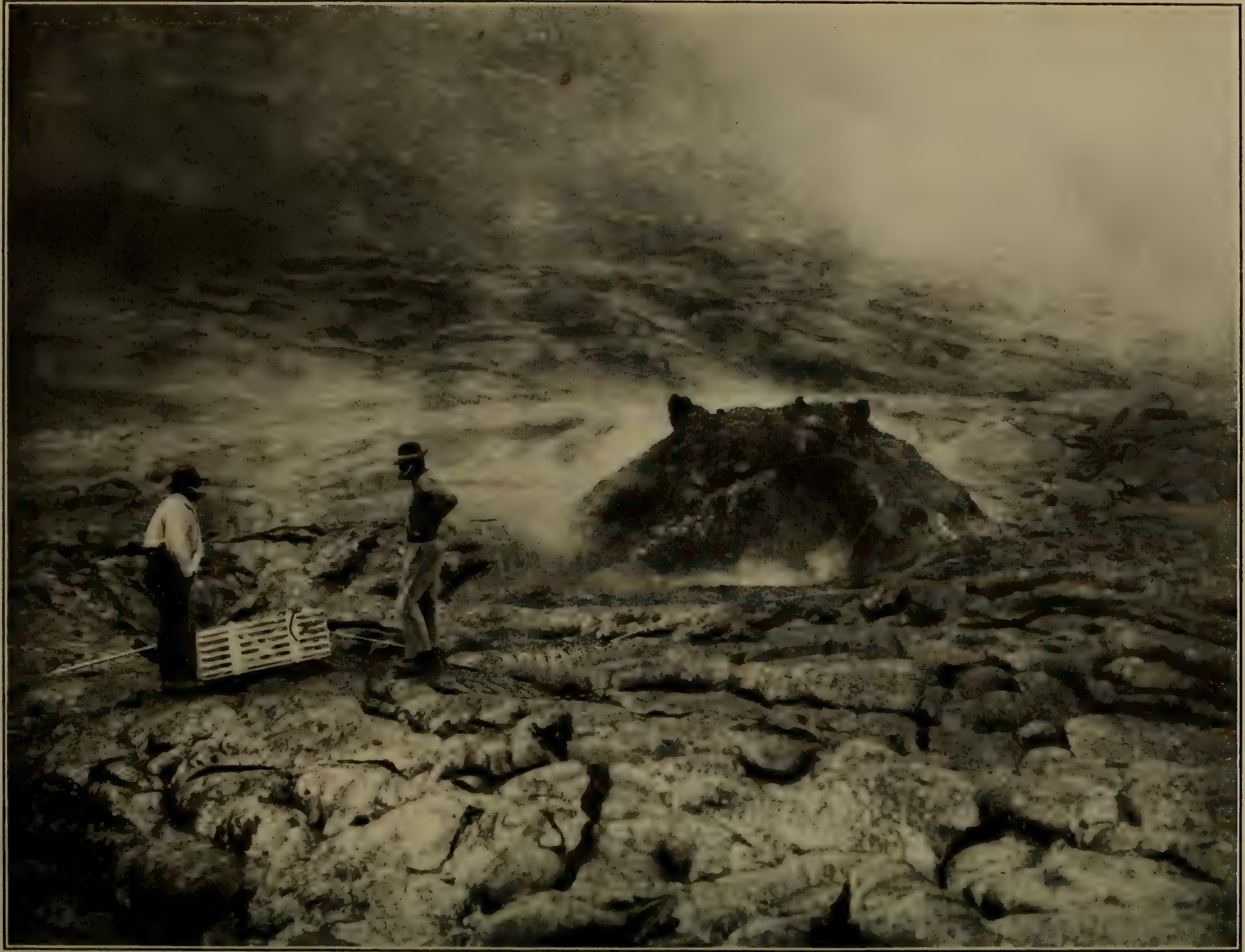
[7] The chemical and physical tests offered by Brun in support of his conclusions (5) and (6), pages 576 and 577, are also somewhat inconclusive. For example, he tests for chlorine with a silver nitrate solution in an atmosphere containing S, SO_2, and SO_3, and notes that it immediately becomes clouded, but mentions no test to ascertain whether it was the chloride or the sulphite which was thus precipitated. Similarly, he nowhere offers a chemical analysis of these particular gases which he collected in tubes at Kilauea, but contents himself with presenting two analyses of other gases pumped from lava fragments reheated *in vacuo* some months afterward.



POSITION OF THE DOME (MAY 28, 1912)

Enlarged from a small photograph to illustrate the position of the dome (↓) from which gases were collected on May 28, 1912, with reference to the lava lake (on the right)



VIEW WITHIN THE ACTIVE PIT, HALEMAUMAU (MAY 28, 1912)

Showing the dome from which gases were collected, the line of tubing on the lava floor, together with the collecting tubes and pump

AN ATTEMPT TO COLLECT THE VOLCANO GASES BEFORE THEY REACHED THE AIR

Be that as it may, in our effort to obtain samples of the gaseous emanations from Kilauea for further study in this laboratory, it was a matter of very great importance to us to endeavor to establish the facts in the case without the aid of inferences of the character above outlined. We therefore entered on a long study of the habit of the volcano, with the purpose of going down on the floor of the crater directly adjacent to the liquid lava, there to collect gases before they had come in contact with the air at all. In the interval between May 1, 1912, and January 1 following but two favorable opportunities for such an undertaking occurred, of both of which we endeavored to take advantage. On the first occasion (May 28, 1912) a column of liquid lava had worked its way up through the shattered floor adjacent to the large active basin and formed an active lava fountain there several feet in diameter. Through its own spattering this fountain quickly built for itself an inclosing wall or dike. When this dike had grown to a completely inclosing dome (plate 19), the gases discharged by the fountain were free to escape only through narrow slits in the dome, and there they could be seen at night burning fitfully, with a pale blue sheet of flame, thereby demonstrating (1) an excess pressure within, and in consequence (2) that the gases released from the liquid lava first came in contact with the air on emerging from these cracks in the dome.

We accordingly made the somewhat difficult descent into the crater without mishap, and two crates, each containing 10 glass tubes of one-half liter capacity each, arranged in a continuous series, were then lowered down to us. To one end of this series of tubes a glass pipe-line was attached, which led directly into one of the cracks of the dome (see plate 20) through which the gas was escaping. The last link of the pipe-line consisted of an iron tube extending into the dome about 12 inches. This iron pipe was also lined with glass up to the very mouth of the crack, so that, except for the 12 inches of iron pipe within the dome, the gases came in contact with no substance other than cold glass and a few pure rubber connectors, which were made as short as possible by abutting the ends of the adjacent tube sections. Inasmuch as the liquid lava contains nearly 10 per cent of FeO, the momentary contact of the gases with the oxidized surface of the iron was not accounted a serious disturbing factor.

The other end of the tube system was connected to a piston pump about 4 inches in diameter, with a displacement of about 2½ liters per stroke to insure a rapid passage of the gases through the tube system.

The gases entered the pipe-line at a temperature of about 1,000°. Their path was through the 12 inches of iron pipe, about 20 feet of glass tubing (pure rubber joints at 4-foot intervals), then through 20 collecting tubes and out through the pump at the back. The pumping was kept up for 15 minutes in order to make sure that the air originally contained in the pipe-line and connecting tubes was displaced by the gases from the volcano, after which the pump and pipe-line were sealed off with pinch-cocks and the crates raised to the rim. In this pipe-line water began condensing with the first stroke of the pump, and at the end of 15 minutes about 300 cubic centimeters had accumulated in the collecting tubes. It was clouded with free sulphur, partly from the original emanation and partly from the action of the iron tube on the sulphur dioxide contained in the emanation.

In arranging this experiment Brun's conclusions were known to us, and accordingly we had provided ourselves with apparatus for collecting fixed gases only. We were wholly unprepared for any which might condense in passing through the collecting tubes. What we obtained, therefore, was a quantity of the fixed gases, which may be assumed to be approximately in the proper quantitative relation one to another, and water, the latter in considerable excess from the fact that it was not pumped through the tubes with the fixed gases, but condensed and remained behind, chiefly in the first three or four tubes. There is, therefore, no way to estimate from the results of this experiment the proportion of water to the total quantity of volatile matter discharged from the lava. Perhaps this should be regarded as a fortunate mischance notwithstanding, for we were thereby enabled to gather a quantity of water sufficient to establish its existence among the volatile ingredients exhaled by the volcano beyond the criticism of the most skeptical. Furthermore, the condensing water by its accumulation in the first tubes served as a kind of wash-bottle for the collection of any soluble material contained in the gaseous emanation.

The next day we began preparations to meet the emergency thus thrust on us by building in the laboratory of the Hawaiian Volcano Research Association[8] an extemporized mercury pump of the displacement type and vacuum tubes especially arranged to meet the conditions which we had found. These tubes were of the same capacity as the individual tubes in the previous experiment (one-half liter), but were provided with a long stem, on the remote end of which was blown a thin glass bulb. The plan was to attach these tubes to a pole of convenient length and to thrust the end carrying the thin bulb into the dome, where the heat might be expected to explode the thin glass immediately, permitting the tube to fill with the gases, and as quickly to seal it again by melting down the broken end. The tubes were dried in contact with phosphorus anhydride and the degree of exhaustion checked by electrical discharge tests from a small static machine. When a number of these tubes had been prepared and everything was ready for a second attempt, the top of the lava dome had fallen in, and the liquid lava in the basin had gone down to such an extent that it offered no further opportunity to collect gases under conditions which should assure original gas without contamination from the air or otherwise. In fact no other opportunity offered until December 4.[9]

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[8] The Hawaiian Volcano Research Association is organized under the general supervision of the Bishop Museum of Honolulu, and is in charge of Prof. T. A. Jaggar, of the Massachusetts Institute of Technology, to whom our most cordial thanks are offered for many courtesies extended to us throughout our work at Kilauea. Mr. F. B. Dodge, an assistant in the association laboratory, accompanied us in the first descent into the crater, and Dr. H. O. Wood, who is in charge of the seismologic work of the station, on the second, both rendering invaluable assistance in carrying out this difficult and somewhat hazardous task.

THE SECOND ATTEMPT TO COLLECT GASES

On December 4, with the lava surface 360 feet below the rim, and therefore even less conveniently accessible than on the previous occasion, a similar dome formed directly on the border of the lava lake, and the second attempt was made to collect a quantity of gas—this time in the vacuum tubes. In order that there might be no possible doubt about the excess gas pressure within the lava dome, the descent into the crater was made at night, when the pale blue flame of the escaping gases could be plainly seen emerging from the crack in the dome. The manner of collecting the gases was exactly that which was planned and described above, and six tubes were filled with gas under these conditions.

On descending into the crater to collect gases from the December dome, it was found that in addition to a long slit or crack across the top, from which the gases were discharging constantly, there was a second opening near the base which was not noticed before the descent, but which gave access to air at the base of the dome and thus behaved like an air blast in a furnace. The gases were therefore partly burned within the dome instead of outside, and the tubes, which were filled at the upper opening, were accordingly found to contain chiefly burned gases—that is, the free hydrogen had become water, the free sulphur had burned to SO_2, the CO appeared as CO_2, etcetera.

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[9] In the meantime one of the authors (Day) was obliged to return to Washington, leaving the other (Shepherd) to finish the task alone.

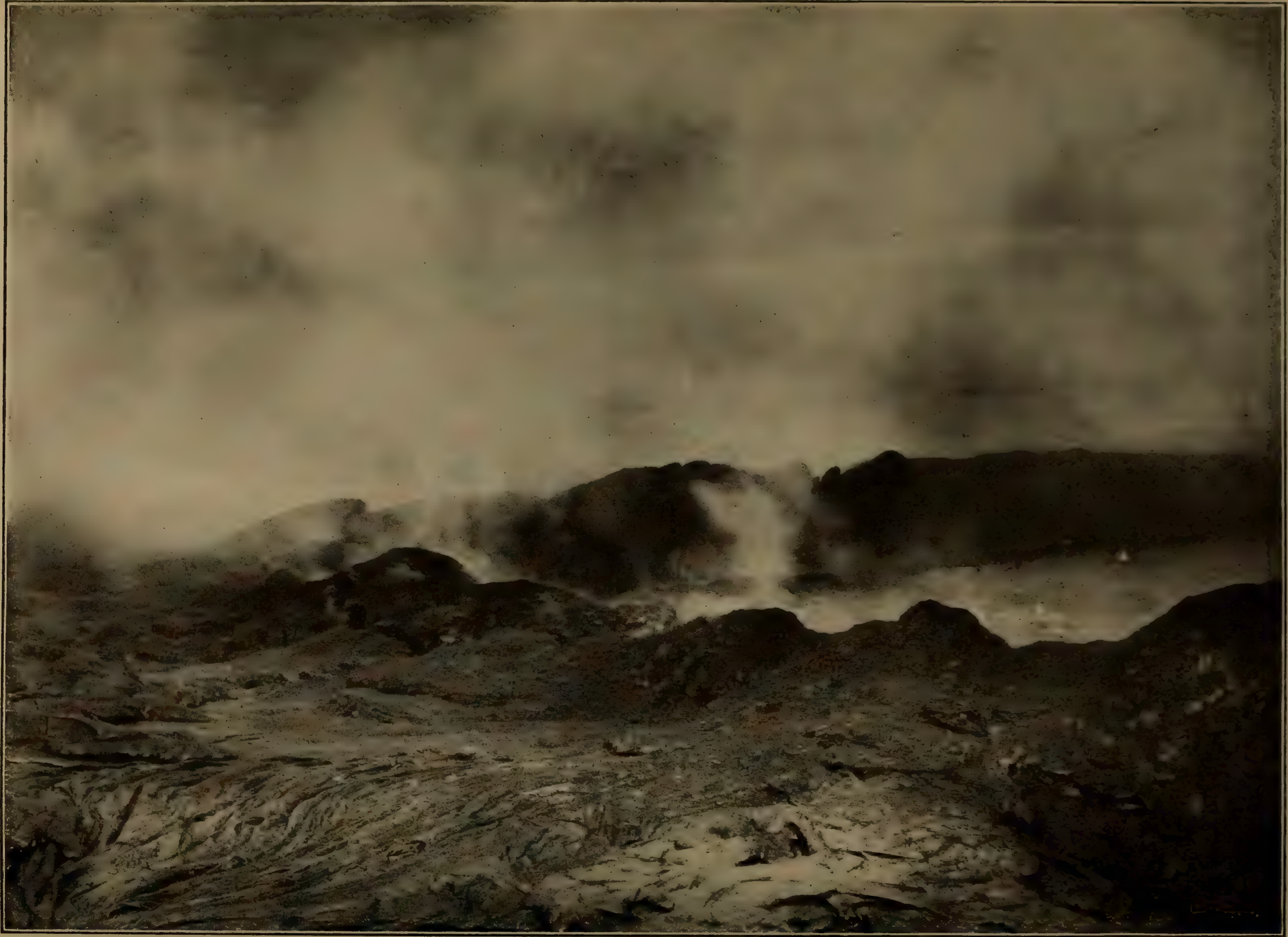
Although the identity and something of the relation of the gases discharged from the basin of Halemaumau can be established from a study of the material collected in May, the determination of the exact proportion of water to the other gases present must await another favorable opportunity. It may perhaps be added that a complete equipment for another attempt lies ready at the laboratory of the Volcano Research Association on the crater rim, but the lava lake disappeared completely from view soon after the December descent was made and has not again reappeared.

Although the continuation of the field studies must await the gracious pleasure of the most fickle of goddesses, it need not delay the prosecution of the laboratory study of the relations between the gases already found or the preliminary discussion of the results thus far attained. Moreover, in the discussion which follows evidence will be offered that the composition of the gases varies within considerable limits, so that the precise proportions of the gases which go to make up the exhalation at any particular moment may prove to be of less importance than was at first believed.

CHEMICAL STUDY OF THE MATERIAL COLLECTED

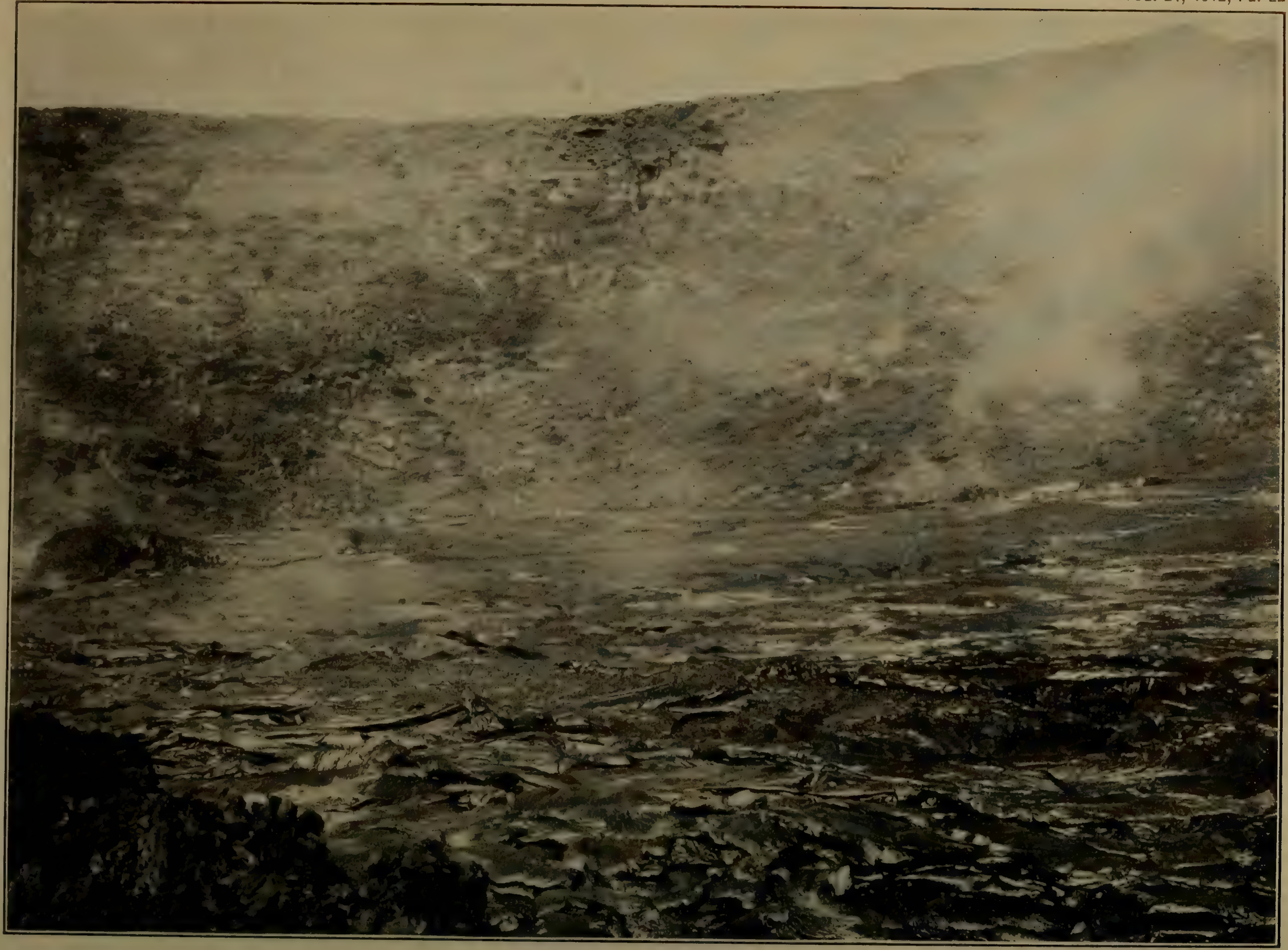
From a physico-chemical viewpoint, the study of volcanic activity centers first on the nature of the participating ingredients, then on the condition of equilibrium or the progress of the reactions taking place between them, as the case may be. At the time of our two visits all the three states of matter—gaseous, liquid, and solid—were found represented. Gases were emitted constantly in great volume, and displayed nearly all the great variety of cloud forms which have been so frequently described in volcano literature except the violently explosive type, which has been rarely or never seen at Kilauea since the advent of the white man (1820). There was a liquid lava basin of oval shape some 600 by 300 feet, inclosed by a lava dike or rampart built up from the surrounding floor of the basin by the tumultuous spattering and splashing of the lava lake (plate 21). Both floor and rampart are frequently overflowed when the lake is high, and again great masses of it fall into the lake and are redissolved when it is low. The floor of the pit at the time of our first descent in May, 1912, had been completely overflowed but three days before and was reasonably level. The fresh lava had solidified to a depth of some 10 inches and was abundantly solid to walk on, but was still uncomfortably hot and the cracks were still glowing.

Surrounding this floor are the walls of the pit, some 200 feet high at the time of our first descent and made up of the exposed edges of suc-



VIEW OF THE LAVA LAKE AT CLOSE RANGE (MAY 28, 1912)

Taken within the crater immediately after plate 20. The inclosing dike due to the spattering of the lava is well shown. A portion of the dike a little to the left of the center of the picture fell into the lake a few moments after the exposure



VIEW OF THE LAVA LAKE AT CLOSE RANGE (JUNE 29, 1912)

Showing also the inclosing wall of the pit. Note the absence of smoke above the active lava (page 585) cessive earlier overflows (plate 22), which individually rarely exceeded 2 or 3 feet in thickness. The (Halemaumau) pit as a whole was about 1,500 feet in diameter, roughly circular in plan, and with nearly perpendicular walls except for the talus pile at the base, which extended about half way up the wall. All these dimensions vary somewhat from day to day and considerably from year to year with the state of activity in the basin. The appearance of the lake and its surroundings is perhaps best shown by a photograph (plate 23) made from a slight elevation above the floor of the active basin on May 23, 1912.

ANALYSES OF THE LAVA

The composition of the liquid lava in the lake and of the solid floor of the Kilauea crater near the Halemaumau pit may be seen from analyses 1-*a* and 1-*b* which follow. The sample 1-*b* was dipped from the middle of the lava lake on July 23, 1911, by Mr. Frank A. Perret and one of the authors (Shepherd)[10] with the help of a cable and trolley, stretched directly across the center of the pit, and appropriate tackle. The sample 1-*a* was taken from one of the recent overflows on the main floor of the Kilauea crater and may perhaps be fifteen or twenty years old. The substantial identity of the analyses with each other and with other recent analyses of the lavas of Hawaii[11] shows that no material change in its composition has taken place in recent years. The most noticeable feature of the new analyses is perhaps the presence of a small amount of molybdenum, which appears not to have been detected hitherto. The analyses were most carefully made by Mr. John B. Ferguson of this laboratory, to whom we take this opportunity to express our thanks.

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[10] This expedition was sent out by the Massachusetts Institute of Technology (Prof. T. A. Jaggar) in the summer of 1911 for the purpose of securing a trustworthy measurement of the temperature in the lava lake. The record of the expedition has not been published.

[11] R. A. Daly: Magmatic differentiation in Hawaii. Journal of Geology, vol. 19, 1911, p. 305.

W. T. Brigham: Loc. cit., p. 33.

TABLE 1

Analysis 1-a

Lava from floor of Kilauea: 40 to 50 per cent glass; 5 to 10 per cent olivine; 5 to 10 per cent feldspar phenocryst; rest very fine crystals. (Merwin.)

	Per cent
SiO_2	50.07
Al_2O_3	13.32
Fe_2O_3	1.92
FeO	9.28
MgO	8.01
CaO	10.64
Na_2O	2.16
K_2O	0.45
$H_2O +$	0.49
$H_2O -$	0.22
CO_2	none
TiO_2	2.70
ZrO_2	none
P_2O_5	0.26
SO_3	none
Cl	0.08
F	none
S	0.11
Cr_2O_3	0.05
MnO	0.16
NiO	0.04
BaO	none
SrO	trace
Li_2O	none
V_2O_5	none
Rare earths	none
MoO_3	trace
Ignition loss	0.36
	99.96
After correction for Cl, etc.	99.89

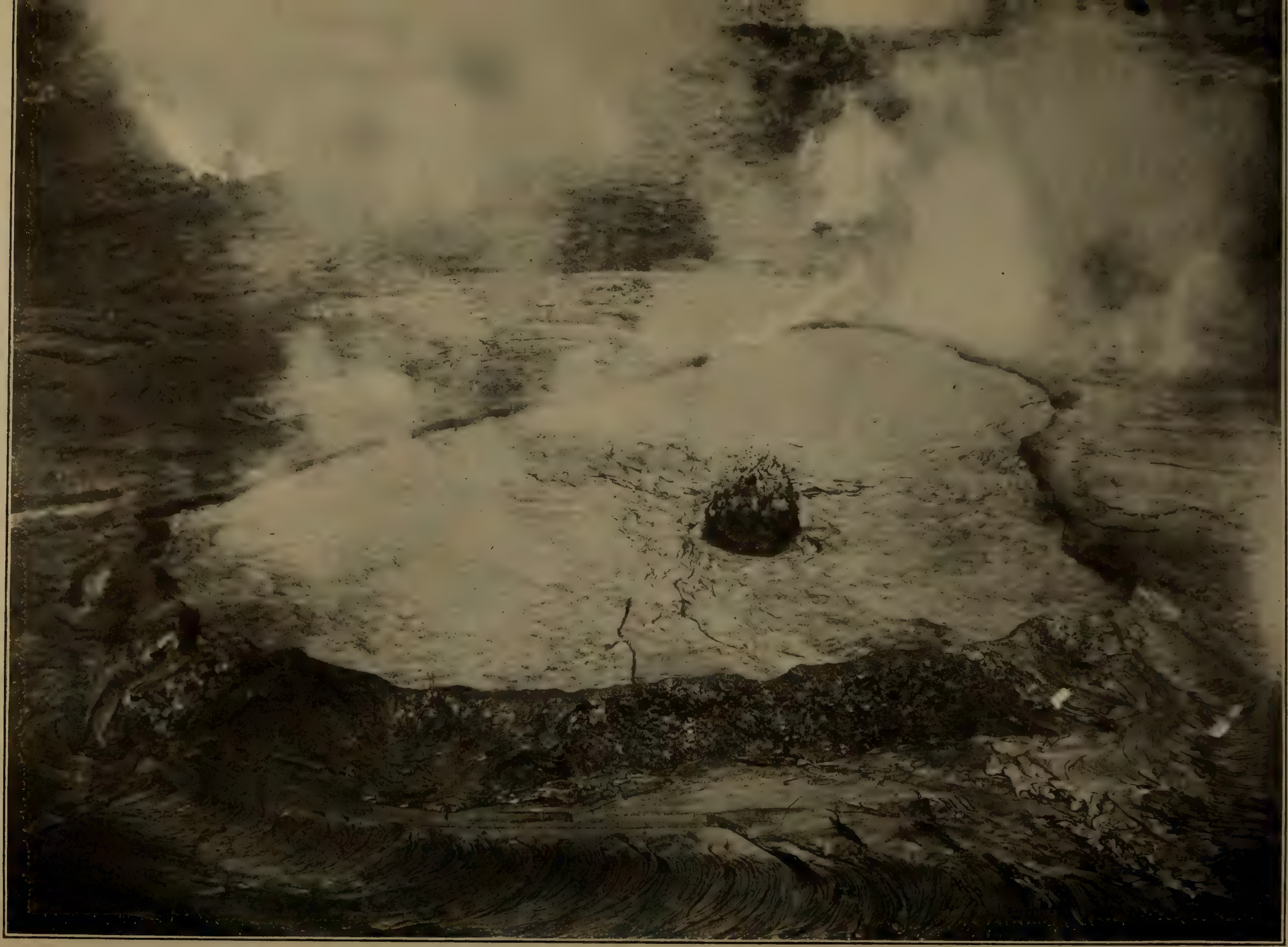
Analysis 1-b

Lava dipped from Halemaumau July 23, 1911. Glass with 1 per cent feldspar and trace of crystals of either magnetite or pyroxene. Index 1.605, lining of bubbles slightly higher. (Merwin.)

	Per cent
SiO_2	49.74
Al_2O_3	12.36
Fe_2O_3	1.64
FeO	10.08
MgO	8.83
CaO	10.88
Na_2O	2.45
K_2O	0.55
$H_2O +$	0.17
$H_2O -$	0.05
CO_2	none
TiO_2	2.49
ZrO_2	trace
P_2O_5	0.41
SO_3	trace
Cl	0.10
F	none
S	0.04
Cr_2O_3	0.04
MnO	0.14
NiO	0.05
BaO	trace
SrO	0.07
Li_2O	none
V_2O_5	0.02
Rare earths	trace
MoO_3	0.01
	100.12
After correction for Cl, etc.	100.08

THE GASES AND DIFFERENT WAYS OF STUDYING THEM

The problem of collecting volcanic gases which are satisfactory from the chemical viewpoint is a much more difficult matter, as has been already intimated. Hot gases of more or less complicated composition discharged from an active volcanic vent into the air undergo immediate and violent chemical and temperature changes, the consequences of which,



VIEW OF THE LAKE AS A WHOLE IN A PERIOD OF MODERATE ACTIVITY (MAY 23, 1912)

Note the overflow both left and right and the formation of ropy lava in the foreground. The bursting bubble is about 30 feet in diameter

with our present limited knowledge of gas relations at these temperatures, can be only partly inferred. It is, therefore, a matter of the first importance to collect the gases directly from the liquid lava or the explosive vents before contact with the air has given opportunity for these alterations to occur. It may very well be that the physical difficulties attending the collection of volcanic exhalations, particularly from volcanoes of the explosive type, will often make it impossible to obtain unaltered magmatic gases for laboratory study, in which case burned gases, or even very dilute mixtures of these with air, may prove to be the only products available for study. In this event the student must perforce bow to the necessities of the case.

Something of the same cautious attitude requires to be maintained toward the study of the flame spectra of burning volcanic gases. The pocket spectroscope is primarily an instrument of preliminary reconnaissance in the field and is sometimes of value, but the pale blue flames of sulphur and hydrogen are extremely difficult to analyze with the pocket spectroscope, and can not be distinguished at all against a bright background of solid or liquid lava. For this reason a more elaborate spectroscopic equipment would not help the matter. Moreover, the gases are much altered or are in process of active alteration before any opportunity for identification is offered, and no estimate of the relative quantity of the various participating gases is possible by this means. Inferences from the chemical study of gases which have been burned by contact with the air while still hot, and inferences from the spectroscopic study of the gases while burning, therefore suffer alike from limitations of principle and should be resorted to only when the difficulty of collecting unaltered gas is insuperable.

These reasons may serve to show why this somewhat elaborate effort was made to collect unaltered gases for laboratory study and why we are inclined to give greater weight to the results obtained from the study of such gases than to many of the earlier studies[12] of volcanic emanations, in which the gases had become altered through contact with the air or otherwise.

The domes from which these gases were collected were built up by the lava itself on the floor of the crater (Halemaumau) and were both chemically and physically ideal gas collectors, being lined with fresh splashes of liquid lava of the same temperature and chemical composition as that from which the gas had just emerged. They formed at the level of the lava lake and, as could be plainly seen after the collapse of the domes, were directly connected with the lake by channels of liquid lava just below the surface crust. The collapse of the entire channel leading to the May dome is shown in plate 24, figure 1, in which an arrow (†) has been placed to indicate the position where the dome stood. The May dome was under constant observation for several days and a considerable portion of the night immediately previous to the collection, during which time there was no cessation of the lava fountain spouting within the dome nor of the flames of the burning gases as they escaped through its cracks. Furthermore, as the larger bubbles rose and burst from the liquid lava within the dome, the jar could be felt on the floor where the collectors stood and the splash could be plainly seen through the cracks.

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[12] e. g., Wm. Libbey: Am. Jour. Sci. (3), vol. 47, 1894, p. 371.

ANALYSES OF THE GASES COLLECTED IN MAY, 1912

The following analyses were made of the fixed gases collected in glass tubes on May 28, 1912, in the manner above described. The statement is given in parts by volume. The tubes were numbered from 1 to 20 in the order in which the gases entered from the volcano. All the tubes contained condensed water (the first—plate 24, figure 2—containing nearly 100 cubic centimeters), of which analyses will be found on page 592.

TABLE 2

The Gases from Halemaumau (Kilauea), May, 1912

Percentages by volume

	Tube 1	Tube 2	Tube 8	Tube 10	Tube 17
Co_2	23.8	58.0	62.3	59.2	73.9
CO	5.6	3.9	3.5	4.6	4.0
H_2	7.2	6.7	7.5	7.0	10.2
N_2	63.3	29.8	13.8	29.2	11.8
SO_2	none	1.5	12.8	none	none
Rare gases	none	none	none	none	none
Hydrocarbons	none	none	none	none	none

THE INFLUENCE OF THE IRON COLLECTING TUBE

In the 15 minutes during which pumping was continued the short length of iron pipe which extended into the dome was partly destroyed by the joint action of the sulphur and SO_2. Owing to the high temperature and the splashing of the molten lava, neither glass nor porcelain would have withstood the ordeal, and a tube of silica glass was, unfortunately, not available; so that iron appeared to be the best material at hand

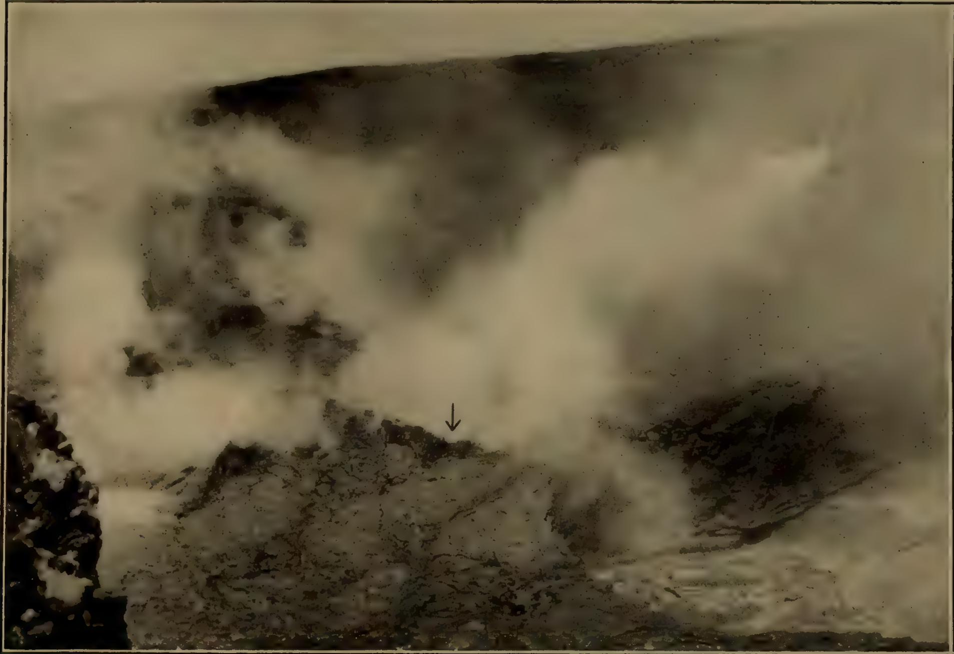

FIGURE 1.—VIEW OF LAKE AND THE SHATTERED FLOOR FIVE DAYS AFTER GASES WERE COLLECTED (JUNE 2, 1912)

Showing (†) place where the dome had stood. Beneath the crack where the cloud issues extends an arm of the lake

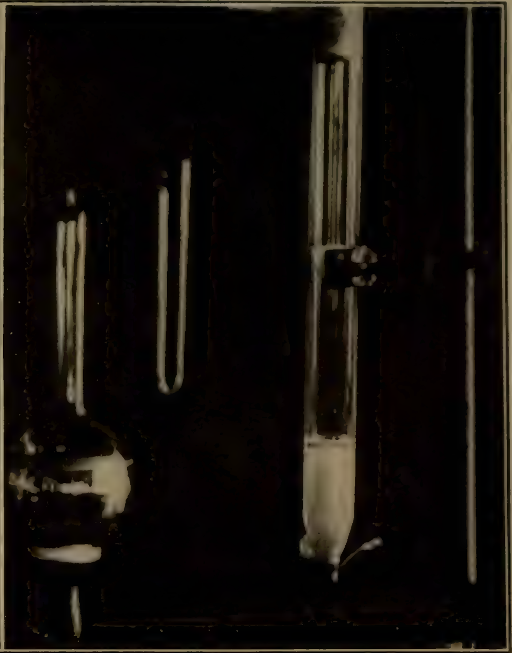

FIGURE 2.—VIEW OF TUBE NUMBER 1 IN THE LABORATORY READY FOR ANALYSIS

Showing condensed volcanic water. The quantity is about 100 cubic centimeters

LAKE WHERE GASES WERE COLLECTED AND TUBE CONTAINING CONDENSED VOLCANIC WATERS

through which to reach the interior of the dome and to insure the capture of the gases at the temperature of emergence from the lava (about 1,000°) before any opportunity for cooling or contact with air had been given.

The effect of this small section of iron pipe on the relations between the gases collected in the tube is not as great as might at first appear. The action of SO_2 on iron at this high temperature is quite vigorous, the iron going over to ferrous oxide and setting free the sulphur. But both these ingredients are present in the lava already, as may be seen from the analyses (table 1), so that no new component is added nor is any new reaction precipitated through the introduction of the iron. It might be assumed, further, that the free hydrogen present would be partly oxidized to water in reducing the ferrous oxide formed from the SO_2 and iron (this is one of the reactions when these components are brought together at this temperature in the laboratory), but if this reaction has had a share in the disposition of our bit of exposed iron we must admit its presence in overwhelming magnitude over the entire inner surface of the dome, which is everywhere lined with liquid lava containing nearly 10 per cent of ferrous oxide. The assumption of this reaction would, therefore, have the immediate effect of establishing the presence of water in quantity among the volcano gases and at the same time relegate the influence of the iron tube to a position of entire insignificance.

There is still further evidence, if more is needed, that the local reactions set up by the iron are of subordinate importance only in their effect on the proportions of the gases collected, and of no effect whatsoever on their identity and chemical relation. Supposing these reactions to have occurred as described, it is then a matter of straightforward computation to show that if the known weight of iron which was dissolved away by the gases, both those which entered the pipe and those which merely played on its outside wall,[13] had reacted in this manner; and supposing, further, that all the products of the reaction both outside and inside entered the collecting tubes (which is obviously impossible), it would have involved pumping through the system some 225 liters of *pure hydrogen* as an equivalent for the iron consumed, and this still falls short of the quantity required to account for all the water collected by more than 40 per cent. Moreover, if the attempt is to be made to account for all the water collected in our tubes through reactions requiring free hydrogen, it is altogether inconceivable that any such quantity of uncombined hydrogen is available in the emanation from the volcano. For if we were to assume that as much as 1,000 liters of volcanic gas (which is a very liberal estimate) passed into the collecting train in the 15 minutes during which the pumping was continued, such a quantity of free hydrogen (375 liters) would be equivalent to 40 per cent of the total composition, a quantity sufficient to form an explosive mixture, on contact with air, of such extreme violence as to change the entire character of the volcanic activity at Halemaumau. It is a fact of general observation that the bubbles of gas which come up through the liquid lava, even when they reach the enormous size of 30 feet in diameter, give no explosion whatsoever.

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[13] The scale on the iron pipe after exposure was found to contain over 85 per cent of ferrous oxide and about 8 per cent of sulphur.

We may therefore fairly conclude, both from the character of the reactions in which the iron might have a part and from the quantity of water collected, that the presence of the iron tube has no considerable significance in relation either to the character or to the amount of volatile material collected.

THE REACTION BETWEEN H_2 AND SO_2 OR CO_2

To this reaction assumed to be going on between H_2 and FeO may be added another and much more important one in which the iron has no part. The free hydrogen set free by the volcano reacts with sulphur dioxide at 1,000° to give water and free sulphur directly. It will also be recalled that carbon dioxide and hydrogen undergo similar reaction at this temperature. This is the familiar water-gas reaction

$$H_2 + CO_2 \rightleftarrows CO + H_2O$$

which has been thoroughly studied by Haber[14] and others throughout the entire range of temperatures found to prevail at this volcano, and may be accepted without limitation as an important factor in the activity which we are studying. It follows directly from this that the chemical analyses of volcano gases offered by Brun in support of his conclusion that the exhalations from Kilauea and other volcanoes are anhydrous, also carry on their face the clear proof that his conclusion is untenable. Neither CO_2 nor SO_2 can be associated with free hydrogen at temperatures in the vicinity of 1,000° without the formation of water. The two analyses offered by Brun of the gases given off on reheating the Kilauea lava show them to be chiefly made up of precisely these ingredients (loc. cit., page 115):

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[14] See, for example, F. Haber: "Thermodynamik Technischer Gasreactionen," p. 158. München, 1905.

Brun's Analyses of Gases obtained from Kilauea Lava when Heated in Vacuo

1		2	
HCl	traces	Cl (libre)	5.58
SO_2	1.7	HCl	1.71
CO_2	50.8	SO_2	4.72
CO	17.3	CO_2	69.09
H_2	28.5	CO	11.60
N_2	1.2	CH_4	0.85
		H_2	6.10
		N_2	0.3

It is, furthermore, noticeable that the analyses here offered by Brun as representative of the gases emanating from Halemaumau do not in any way agree with the composition of the gas which we obtained from liquid lava. He finds, for example, in one analysis more than 7 per cent of chlorine in one form or another, where we find 0.02 per cent or less. He obtained about 5 per cent of SO_2, whereas SO_2 during our visit was perhaps the most notable gas evolved from this crater.

THE RELATIVE QUANTITIES OF THE CONSTITUENT GASES

Leaving now the question of the identity of the gases discharged by the lava at Halemaumau, we should perhaps turn for a moment to the consideration of their relative quantity, which, as already intimated, is not so well established by our samples because of the unexpected presence and condensation of the water in the collecting tubes.

In addition to the presence of the iron tube and its possible effect on the total quantity of water and of free sulphur collected in our tubes, which has been discussed above, our analyses of the gases (page 588) are subject to a second limitation which is at once obvious. When the pumping had been completed, the collecting tubes each contained a quantity of the condensed water, in which the fixed gases are individually soluble in varying degree both during and after cooling. There is also some reaction between the gases and water. The long period which elapsed between the date of collecting the gases and their analysis in Washington after the close of the field season (nearly a year) gave opportunity for these readjustments to proceed practically to completion. The SO_2, for example, has gone over in part or altogether to SO_3 and gone into solution, and only two of the five tubes analyzed now show SO_2 as such, Moreover, the resulting acid solution may have reacted to a limited extent on the glass tube, and accordingly be responsible for all or a part of the alkalies, lime, and almuina shown in the analyses of the water (page 592).

Preliminary Analysis of one Tube of Gas in Honolulu

For this reason some importance attaches to a preliminary and very hasty analysis of the contents of one of the tubes (number 3) made but four days after the collection, for which the College of Hawaii most courteously extended the facilities of its chemical laboratory at Honolulu. This preliminary analysis was undertaken solely as a precaution against the consequences of a possible total loss of the material collected through accidents of transportation.

Owing to the limited facilities, it was not possible to make a complete analysis; but in tube number 3, shaking with water reduced the total volume of gas by *51.6 per cent,* which may fairly be assumed to represent the SO_2 in this particular tube. As there was a quantity of the condensed volcano water in the tube already, this merely reveals the quantity of SO_2 in excess of the quantity already taken up by this water. The carbon dioxide of this tube amounted to 39.8 per cent, but was probably contaminated with some SO_2. The CO amounted to 5.5 per cent. The hydrogen and nitrogen could not be determined, but there was not enough hydrogen in the residual gas to form an explosive mixture when mixed 1:1 with air. The water in this tube gave a very slight turbidity with acid silver nitrate and a slight precipitate of SO_3. This latter represents the amount formed in the tube in the time which elapsed between the collection and analysis (four days). This tube gave no test for titanium.

Hydrocarbons could not be detected in any of the tubes.

The Material Present in the Water

The water which was collected in the first tubes of the series may fairly be assumed to contain practically all of the halogens. The analysis of this water is given in table 3.

Table 3

Analyses of Material contained in the Water collected in the Tubes

	Tube 1	Tube 2	
Na_2O	0.0214 grams	0.031 grams	The major portion of these may have come from the glass or from Pele's hair.
K_2O	0.0102 "	0.011 "	
CaO	0.0120 "	0.14 "	
Fe_2O_3 Al_2O_3	0.080 "	0.010 "	
Cl	0.220 "	0.206 "	
F	0.565 "	0.492 "	
NH_3	0.0018 "	none "	
TiO_2	0.005 (?) "	none "	
Total S as SO_3	0.480 "	0.508 "	

It is not improbable that most of the alkalies, lime, and alumina have resulted from the action of the acid liquid on the glass tubing, but it is of the greatest importance to establish the fact that the entire quantity of gas pumped through the "wash bottle" yielded no more than 0.4 gram of chlorine. If this be calculated in the form of gas, it will correspond at most to 0.02 per cent, assuming that approximately 1,000 liters of gas were drawn into the tubes. Fluorine seems to be present in about twice this quantity, but in no sense can these halogens be regarded as forming more than a very minor part of the crater exhalation.

RARE GASES

In the progress of the analyses, after all the active gases had been removed from the several tubes analyzed, there remained an inactive residue which, of course, consisted mainly of nitrogen, but which might be supposed to contain traces of argon, helium, or other of the rare inert gases, should any such chance to have been present in the volcano emanation. For the determination or detection of these several of the residues were brought together in a spark tube and exposed for several hours, in the presence of oxygen, to an alternating current spark discharge of considerable intensity. When the volume of residual gas could no longer be diminished by this means, there remained a final residue of 75 cubic centimeters of gas, which was forwarded to Prof. R. W. Wood, of Johns Hopkins, who very kindly offered[15] to make a spectroscopic examination of it for traces of the rare gases. The search yielded a decisive negative result. No lines characteristic of any of the rare gases could be found with the spectroscope, nor did exposure to charcoal at the temperature of liquid air leave any residue whatever. The gas examined was, therefore, all nitrogen. Subsequently the residues (15 cubic centimeters) from another group of the tubes were treated in the same way and forwarded to Professor Wood, who was again able to detect nothing but pure nitrogen. It appears to be definitely established, therefore, that the gases collected from Halemaumau in May contain nitrogen but no argon. This affords a most desirable confirmation of our belief that the volcano gases were successfully collected before they had come in contact with atmospheric air at all, and were therefore entirely uncontaminated either by reaction or admixture with it. It also offers support to the view that the volcanic nitrogen is not of atmospheric origin—to which further allusion will be made in the concluding paragraphs.

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[15] We desire to take this opportunity to thank Professor Wood for courteously offering to examine these gas residues. The Geophysical Laboratory possesses neither the equipment nor the special experience necessary to undertake a spectroscopic study of this critical character.

THE GASES COLLECTED IN DECEMBER, 1912

From the gases which were collected in vacuum tubes on December 4, 1912, much less information is obtainable than from the May collection, in spite of the more elaborate preparations made for the second attempt. This was wholly due to the fact already mentioned, that the dome from which the December gases were collected proved on near approach to be an imperfect one, which permitted the entrance of air and a partial combustion of the gases within the dome. Six individual vacuum tubes (two of one-half liter capacity and four of 250 cubic centimeters) were automatically filled and sealed off within this dome and were brought to Washington in safety, but were found on opening to contain mixtures of volcano gases and air, such as might be expected from exposure to the temperature at which they were collected (about 1,000°). There is, of course, no more reason for expecting the chemical reaction between the gases and air to have proceeded to an equilibrium than in the case of the reactions between the volcanic gases alone, whence the analyses of the gases contained in these tubes may be expected to show very variable proportions.

In stating the analyses the free oxygen found has been subtracted, together with a corresponding portion of the nitrogen appropriate to the normal composition of air. Probably more of the nitrogen should have been subtracted as an equivalent for the oxygen taken up in the combustion of the sulphur products and carbon monoxide, but the amount would be difficult to fix in view of the reactions between the volcano gases themselves and it has not been attempted. The analyses at best add but little to the knowledge already obtained.

TABLE 4

Analyses of Gases collected in December, 1912

Percentages by weight

	Tube 2	Tube 3	Tube 5
CO_2	49.6	33.7	45.4
N_2	24.1	32.1	21.3
H_2O	26.2	26.6	29.7
SO_2	none	7.6	3.5
Cl	trace	none	trace
F	none	none	none

If we make the only available assumption, namely, that the oxygen which is now present as water, if it came from the air, must have left behind a corresponding amount of nitrogen, then the amount of nitrogen found in these three vacuum tubes is in every case two or three times *too small.* For example, in tube number 2, if all the oxygen now contained in the water came from admixed air, there should have been at least 240 cubic centimeters of nitrogen in this tube instead of 74 cubic centimeters, as actually found. There is but one conclusion, namely, that only the minor portion of the water found in the tubes was formed through reaction with atmospheric oxygen. Here again, therefore, we have corroborative evidence of water emanating directly from the liquid lava.

None of these vacuum tubes gave a test for ammonia, which is not surprising, since the water collected in May showed only a trifling amount. With the possible exception of 5 milligrams of insoluble residue found in tube number 1 of the May collection, no titanium was present. The other tubes of the series yielded none on test.

The Hot Emanations from Cracks about the Halemaumau Crater

It was thought desirable to collect and analyze the gases from a number of the hot cracks which occur outside the rim of the Halemaumau pit (see plate 17) for comparison with the gases exhaled from the liquid lava. One of the cracks forms an almost complete ring around the pit at a distance of about 150 meters from the rim. While this crack appears practically continuous, there are a number of points where the gaseous exhalations are much more voluminous than at others. The small steam cloud in plate 17 comes from this crack. The temperature of the gases obtained at points on this circular crack and some 10 feet below the surface were quite uniformly between 190 and 200°.

At the most noticeable of these "hot spots," locally known as the "Devil's Kitchen" or "Postcard Crack," and situated northeast of the Halemaumau pit, the surface lava flows are much decomposed and consist of a coarse, somewhat sandy, mixture of calcium sulphate, alum, ferric sulphate, and much free sulphur. In the gaseous exhalation the amount of SO_3 occurring as such is relatively high, while CO_2, SO_2, and free sulphur are also present in large quantities. A vacuum tube filled at this point yielded in weight per cents:

CO_2	3.64	(per cent by weight)
O_2	19.54	" " " "
N_2	66.71	" " " "
H_2O	9.74	" " " "
SO_3[16]	0.37	" " " "

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[16] The total sulphur computed as SO_3.

Other tubes which were filled by pumping at this crack were found to contain fixed gases as follows:

CO_2	5.8	(per cent by volume)
O_2	18.2	" " " "
N_2	76.0	" " " "

while the water (about 20 cubic centimeters) yielded:

Cl	0.0513	gram
F	0.0079	"
SO_3	0.328	"
NH_3	none	"

Another spot of great gaseous activity occurs in this circular crack near the terminus of the automobile road and southeast of the center of the active pit. The vacuum tube taken at this point yielded:

CO_2	8.12	(per cent by weight)
O_2	14.58	" " " "
N_2	51.20	" " " "
H_2O	25.49	" " " "
SO_3	0.59	" " " "
Cl	undet.	" " " "

The water contained in the tube which was filled by 15 minutes pumping at this point (amounting to about 15 cubic centimeters) yielded the following:

Cl	0.0298	gram
F	none	"
SO_3	0.656	"

50 meters to the northeast of this point, along the same crack, the gas obtained was merely moist air, with a trace of SO_2 and uncertain traces of Cl.

About 100 meters south of the terminus of the automobile road is a moist region, where the decomposed lava rock was found to be more or less saturated with sulphuric acid, the decomposition products being black rather than the bright sulphur yellow prevailing at the points above described. A vacuum tube taken in this region, which is again on the circular crack surrounding the pit and nearly due south of it, yielded:

CO_2	9.64	(per cent by weight)
O_2	18.18	" " " "
N_2	63.85	" " " "
H_2O	7.81	" " " "
SO_3	0.51	" " " "
Cl	none	" " " "

The water condensed in a tube filled by pumping at this point yielded about 3 milligrams of chlorine, but no fluorine.

With regard to the chemical products along this circular crack about the crater basin of Halemaumau, we can sum up by saying that water, although no doubt partly of meteoric origin, was always present at the time of our visit, and the gases were prevailingly high in carbon dioxide, sulphur dioxide, and sulphur trioxide. Only at the automobile road terminus was chlorine found to be present in an amount sufficient to show appreciably in a field test.

Cracks farther removed from the Halemaumau pit show in some cases small amounts of SO_2, but more frequently exhale merely steam. Thus in caves where stalactites are forming at a temperature of about 40°,[17] the gas present was in all the cases examined merely air and steam and contained no more CO_2 than is normally contained in the air. The formation of the stalactites in this cave is accompanied by the formation of gelatinous silica in the presence of some kind of green algæ. As might be expected, neither carbon monoxide nor hydrogen was detected in the gases taken from these cracks.

Sublimation and Decomposition Products

Numerous samples of decomposed lava were taken from various points around the crater where the alteration of the surface lava is conspicuous. While the examination of these is not complete, the preliminary results can be summed up by saying that the samples consist primarily of the products to be expected from a sulphuric acid decomposition of the usual basic lava. In most of the places where these samples were gathered the surface is constantly bathed by the volcanic cloud carrying SO_2, SO_3, and free sulphur, together with steam; which ingredient predominates is of no particular interest, so far as the general problem of surface alteration is concerned. In addition to the gaseous products, the breaking down of the lava results in ferric sulphate, which is formed more or less rapidly from the oxide in presence of steam. Alum occurs at favorable places over most of the main floor of the Kilauea crater, but the amount is relatively small. Gypsum is perhaps the most common decomposition product which is left, and this occurs all over the crater. Projecting lava points on the under side of a lava block will often be found tipped with small crystals of gypsum.

Since the gases collected point uniformly to the conclusion that the amount of chlorine given off by the crater at the time of our studies was relatively insignificant, it seemed worth while to look for it, as Brun had done, in the older lava which had been exposed to the fumes of the crater for several years. A specimen of lava was accordingly taken on the lee side of the crater rim, where it had been fumed with the gases carried over it by the trade-winds for 20 years or more. This lava in a 2-gram sample yielded no test for chlorine. This result is not as satisfactory as it might otherwise be from the fact that the major portion of the exhalation of the volcano is SO_2, which when combined with water readily changes to sulphuric acid and would tend to drive the chlorine out of any combinations which it might form. It constitutes, nevertheless, a plain indication that the amount of chlorine actually evolved is insignificant.

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[17] W. T. Brigham: "The Volcanoes of Kilauea and Mauna Loa on the Island of Hawaii," p. 29. Honolulu, 1909.

DISCUSSION OF RESULTS

GENERAL CONCLUSIONS

In so far, then, as this reconnaissance yields final results, it shows that the gases evolved from the hot lava at the Halemaumau crater are N_2, H_2O, CO_2, CO, SO_2, free H, and free S, with Cl, F, and perhaps NH_3, in comparatively insignificant quantity. No argon or other rare gases and no hydrocarbons were found.

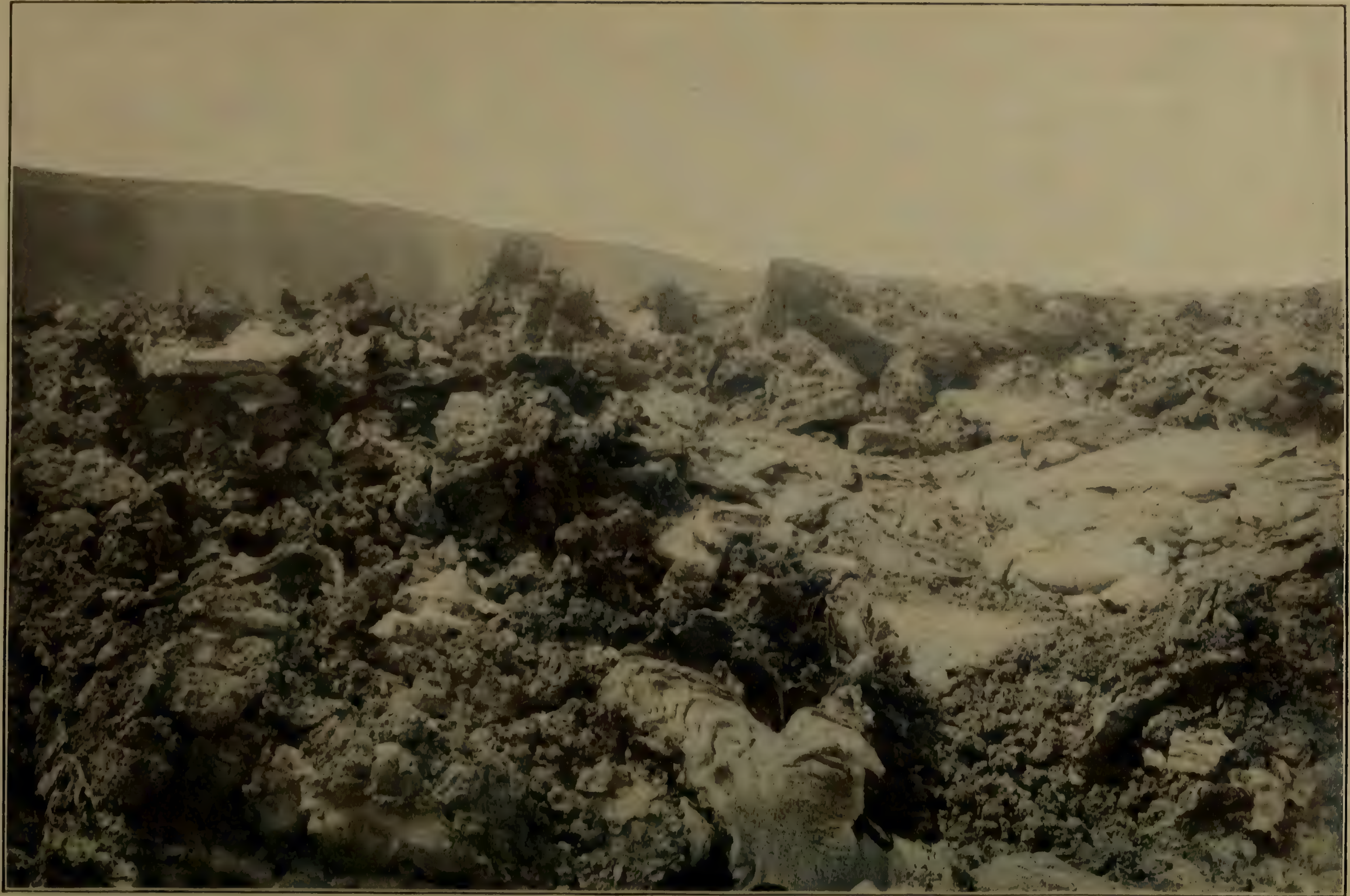
THE EFFECT OF THE REACTIONS BETWEEN THE GASES

The first plain conclusion which follows from the discovery of this particular group of gases associated together at a temperature of 1,000° or more is that they can not possibly be in equilibrium there, and that chemical action between them is still going on. Whatever may have been the previous opportunities for chemical readjustment among the gases as they rose in solution with the magma and were gradually set free with the diminishing pressure, they are still in process of active reaction when discharged into the air. Free sulphur, for example, could not have remained in permanently stable association with CO_2; neither could free hydrogen be found in stable association with CO_2 and SO_2 at 1,000°.

THE EFFECT OF THE EXPANSION OF THE GASES

Moreover, as the pressure continued to diminish during the progress of the upward movement, the quantity of gas released from solution, and therefore free to enter into new relations, must have been constantly and rapidly increasing up to the moment of discharge into the air.

Two consequences follow from the continuation of this operation, which are thermally opposite in sense. First is the rapid expansion of the gases with the release of pressure, which is a cooling phenomenon, and



AA LAVA ON THE MAIN FLOOR OF KILAUEA CRATER (JUNE 22, 1912)

About 500 meters northwest of Halemaumau which, if the expansion take place suddenly from a high pressure into the air, might finally be extremely rapid.

AN EXPLANATION OF THE FORMATION OF AA LAVA

Parenthetically, it may be noted in passing that such rapid expansion and consequent cooling when occurring suddenly at the surface may very well be the sufficient cause of the Aa lava formations. Great blocks appear to have cooled in this way so rapidly that no opportunity was given for the suddenly projected and rapidly expanding lava outbursts to "heal" and resume liquid flow. The projected masses are cooled almost instantly throughout their mass and remain discrete blocks of the roughest and most ragged outline (plate 25), which are pushed forward thereafter in a manner which has been likened to a "moving stone wall," beneath which the advancing liquid can rarely be seen. This hypothesis of the manner of formation of Aa lava has encountered no limitation from a field examination of Aa flows at the point of outbreak, and enjoys still further confidence from the fact that this is almost the only conceivable method of bringing about a nearly instant cooling throughout the mass of a very large block of lava. (Aa blocks are sometimes reported to reach the size of a small house.) Any manner of cooling from the outside inward in such masses must have resulted in much mechanical deformation during the forward movement after the surface had "set," causing rupture and outbursts of imprisoned liquid, none of which were found in the field.[18]

The rate of cooling of gases expanding adiabatically has been especially emphasized by Daly,[19] who has contended that when the liquid lava finds exit through a long and rather narrow pipe, like the vent at Halemaumau, the pressure must diminish rapidly as the lava rises, and the temperature must fall rapidly in accordance with the law of adiabatic expansion. In order to maintain such an exposed surface basin in the liquid state, it is then necessary to postulate a very high temperature for the lava far below the surface,[20] but this has serious difficulties because of the chemical complications which would follow from it.

CHEMICAL REACTION BETWEEN THE GASES

The second consequence of the gradual release of gases is the interreaction between the gases thus set free in constantly increasing quantity as the surface is approached. These reactions are accompanied by evolution of heat, which obviously operates to raise the temperature of the surrounding lava so long as the reacting gases remain in contact with it. The heat generated by these gas reactions, in the region near the surface where the amount of gas is large, may well be much more than sufficient to counteract the cooling effect of the expansion within the rising lava column, which may thus become hotter and not cooler as it approaches the surface.

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[18] For other explanations of the formation of Aa lava see Green, loc. cit., p. 171; Hitchcock: "Hawaii and Its Volcanoes," p. 282; Dana: "Characteristics of Volcanoes," p. 241.

[19] R. A. Daly: "The Nature of Volcanic Action." Proc. Am. Acad. Sci., vol. 47, 1911, p. 84.

[20] Daly has calculated a temperature gradient of 2,000° per 37 meters of depth for the rate of cooling of the gas alone, but the calculation takes no account of the relatively enormous mass of adjacent lava which must be cooled by the gas.

Precise figures can hardly be given for the difference in magnitude between the two forces which have been assumed to oppose each other here, the adiabatic cooling on the one hand and the heat of reaction between the gases on the other, for we do not yet know what all the reactions are in such a complicated chemical system, nor do we possess any knowledge of the height of the lava column through which the gases are free to react. In fact, if the tube which feeds the volcano from below be supposed to contain both ascending and descending columns of liquid lava of widely variable temperature (Daly) in which the circulation is primarily controlled by the (relatively very large) differences of specific gravity, then it is indeed questionable whether the common equations for adiabatic expansion find application here at all. In any event, if we may assume such reactions to be going on between the gases as:

$$H_2 + CO_2 = CO + H_2O + 10{,}000 \text{ calories (Haber)}$$

or

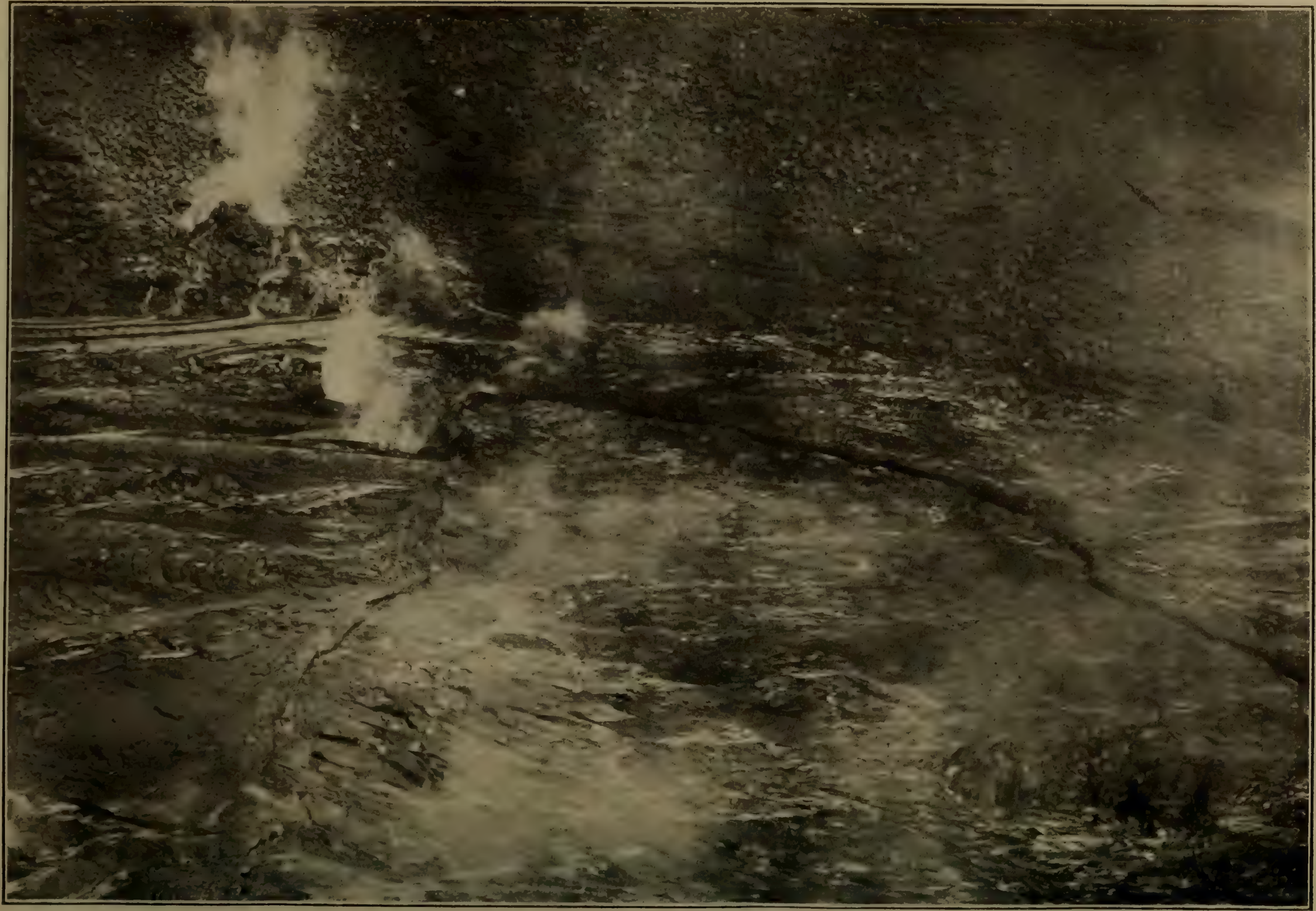
$$CO + \tfrac{1}{2}\, O_2 = CO_2 + 68{,}000 \text{ calories (Haber)}$$

or the reaction between gas and lava:

$$3FeO + H_2O = Fe_2O_4 + H_2 + 15{,}400 \text{ calories (Chamberlin)}$$

then the effect of adiabatic cooling is certainly of negligible magnitude in comparison with these. This is reasoning far beyond the data now in hand, but it serves to show that there is no cooling effect of comparable magnitude with the heating effect of the reactions going on within the active lava.

If the reactions quoted above afford a proper measure of the order of magnitude of the heat quantity thus released by chemical reaction within the tube and surface basin of the volcano, we have here happened on an enormous store of volcanic energy which reaches its maximum temperature at the surface itself. It is by no means certain at the moment that this discovery throws any new light on conditions far below the surface, except perhaps to relieve us of the necessity of postulating extreme tem-



VIEW OF THE LAVA LAKE (MAY 22, 1912)

Showing a cascade which burst from the talus pile on the northwest side of the basin but a few moments before this picture was taken. The cascade is about 40 feet high. Note the lava streams flowing from it to the left. This cascade continued to flow for three days peratures for the lava chambers below, which on other grounds must be considered highly improbable.[21]

VARIATIONS IN THE COMPOSITION OF THE GASES

In full accord with the positive conclusion that these particular gases can not exist together in stable equilibrium at the temperature at which they are found, but are in process of active reaction, the record of the analyses shows their composition to vary from one tube to another. Successive tubes collected from the volcano at the same time (table 2, page 588) do not show the individual gases to be present in the same proportions, but rather in proportions which change with every bubble which bursts from the liquid basin.

VARIATIONS OF LAVA TEMPERATURE RESULTING FROM THE GAS REACTIONS

Further confirmation of the same conclusion is found in the observation, already noted elsewhere, that when the gases given off by the lava increase in quantity (plate 27), the quantity of lava (lava level in the basin) remaining the same, its temperature *increases,* and, conversely, when less gas is discharged through the lava this temperature *diminishes again.* During the period of our visit in 1912 this change in the temperature at the surface of the active lava in the basin amounted in maximum to 115° (June 13, 1912, 1,070°; July 6, 1912, 1,185°), and is therefore much greater than could be explained in so large a basin by fortuitous conditions of measurement. This absence of equilibrium and consequent variability of composition is also in accord with the observations of Perret and others at Vesuvius, that the relative proportions of the gases vary greatly with the condition of the crater.

EXPLOSIVE LAVAS (BRUN)

From the same viewpoint the laboratory observations of Brun on "live" or "explosive" lavas and, in contradistinction, "dead" lavas acquire new and rational significance. In all the experience of the Geophysical Laboratory with the thermal study of silicates, we have found no natural rocks or minerals which did not set free gases in considerable quantity when heated in the laboratory to a temperature high enough to melt their chief constituents. Chamberlin,[22] in his elaborate series of analyses of the gases contained in rocks, seems to have had the same experience. If these studies together represent sufficient breadth of experience to justify a sweeping conclusion, then there are no "dead" rocks, meaning thereby igneous rocks, which no longer release original volatile ingredients when heated to melting. On the other hand, if we admit the nearly or quite universal distribution of gaseous ingredients in igneous rocks, but suppose these gases were in equilibrium with each other throughout the solidification period, then reheating in the laboratory could discover no "explosive" rocks. The distinction "dead" rocks and "live" or "explosive" rocks loses all significance so long as it applies merely to rocks containing gases *in virtual equilibrium* with each other, which merely release the gas when heated. But immediately we understand that in lavas carrying gases in solution or mechanical imprisonment the gases shut up therein may react together, with release of heat, the moment they are free to do so, "explosive" lava has a definite meaning, and Brun's experience (loc. cit., p. 55), that "once the expansion has commenced nothing [for example, withdrawal of the source of heat] can stop it," becomes a most illuminating one. Rapid expansion of the reacting gases, together with the weakening of the inclosing walls through the accession of heat thus supplied from within may very well produce explosive phenomena, in the sense in which Brun used the term, either in nature or in the laboratory. It is otherwise somewhat difficult to see how simple adiabatic expansion of a gas inclosed in walls of obsidian, which are very viscous even at very high temperatures, can produce "explosions" in the manner postulated by Brun.

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[21] Whether these gas reactions may serve as a source of heat through which to point the resemblance between volcanic phenomena and geyser action (Daly) must be assigned rather to the realm of geologic speculation. At all events, the superficial phenomena at Kilauea would seem to find a serviceable explanation without requiring any of the ejecta except the gases to be of deep-seated origin. Indeed, the outbreak in May, 1912, of a lava stream from the talus immediately adjacent to the lava lake and some 40 feet above its level (plate 26) would seem to necessitate differences of pressure, and therefore separate lava chambers, but short distances below the surface, in much the same thermodynamic relations as those supposed to exist between neighboring geysers of different height and character. Hot gases from a common source percolating through chambers, such as appear to honeycomb the Island of Hawaii, and reacting exothermally throughout their journey as actively as a Bunsen burner, would appear to offer sufficient amount and variety of power to accomplish all the visible activity now seen there.

WATER AND THE BASIC MINERALS

There is another conclusion which has been freely offered by those who hold to the view that H_2O can not be present as such in the emanations from active volcanoes, of which a statement may be found in the quotation from Green in the opening paragraph of this paper. It states that "the basic minerals themselves give no indications, in the main eruptions, of having been in contact with water, *highly susceptible as they are to such an influence.*"

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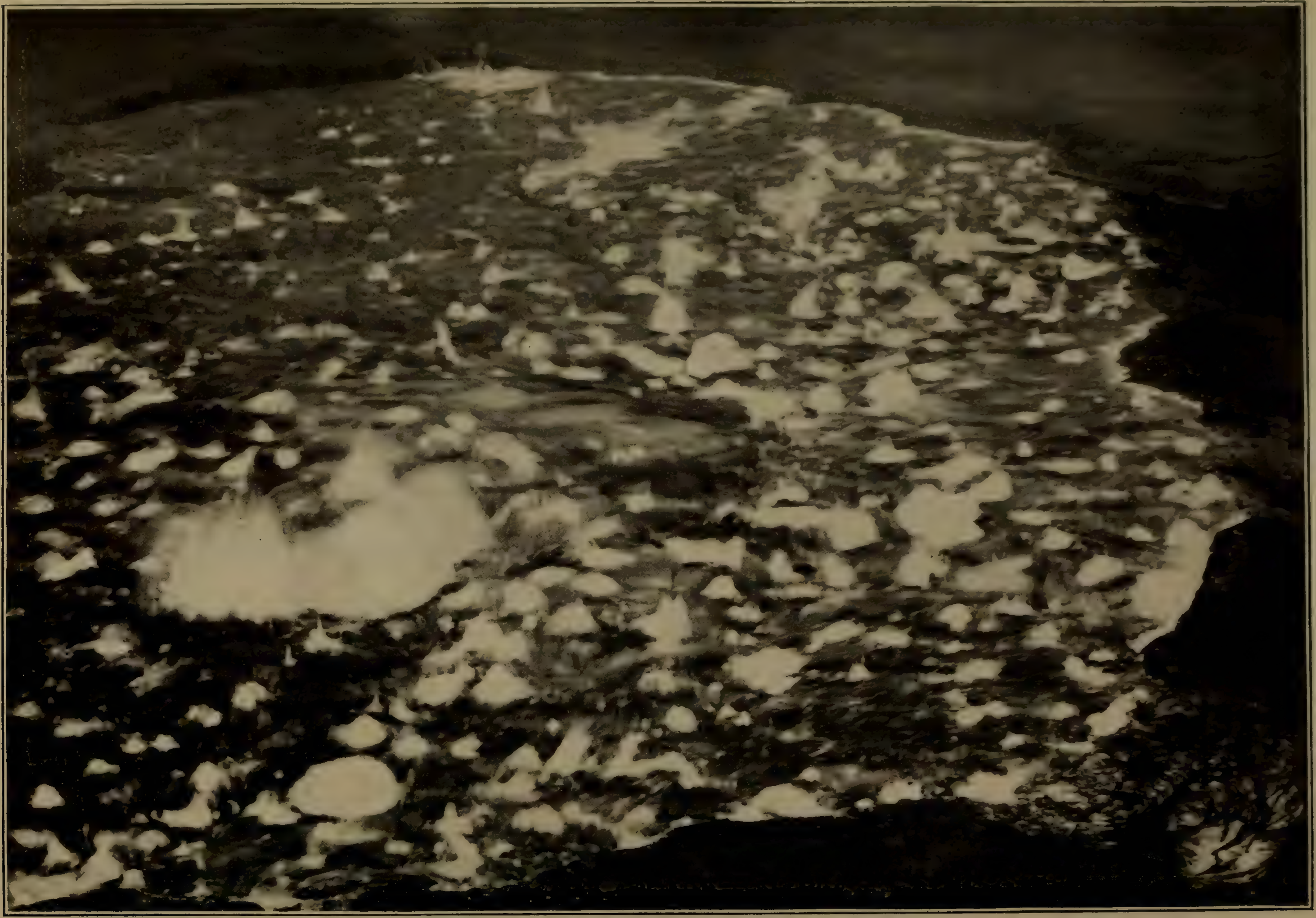
[22] R. T. Chamberlin: The gases in rocks. Publications of the Carnegie Institution of Washington, No. 106.



VIEW OF LAVA LAKE DURING PERIOD OF MAXIMUM ACTIVITY (JULY 8, 1912)

This picture was taken at night by the light of the lava itself. Note the different directions of flow within the basin

It appears reasonably certain that the italicized portion of this quotation (italics are ours) is dictated by the relation between basic rock, liquid water, and air at comparatively low temperatures, and to this extent it may very well be true. In the active volcano Kilauea, however, we are dealing with gaseous H_2O at a temperature above 1,000°; this is quite another matter. It is a part of our program to endeavor to supply the lack of proper data about the relation between the several gases found and the chief ingredients of the liquid lava, and in view of the absence of such data at the present moment the question raised can receive no very complete answer. It is, nevertheless, a comparatively simple matter to bring the powdered lava and water together at 1,100° in the absence of oxygen. The result appears to support our view, for after several hours of the most intimate contact between the gaseous H_2O and the lava no chemical change whatever could be detected either in the "basic minerals" or the water. In so far as a qualitative experiment of this kind may be regarded as conclusive, this lava is not appreciably affected by water at the temperatures which obtain in the lava lake up to the time when the water leaves the lava and is discharged into the air. Pending the acquisition of more detailed data, therefore, we may leave this question in abeyance, with reasonable confidence that it will be found to be in full accord with the fact otherwise established, that water is present and participates actively in the volcanic activity at Kilauea.

ORIGIN OF THE WATER

If we now grant that water is present as an active ingredient of the liquid lava, in view of the positive character of the evidence offered, then it becomes pertinent to inquire whether this water is of magmatic or of meteoric origin. Obviously, to this question no such positive answer can be returned as that which was offered in support of the main thesis of this paper. It is conceivable (1) that water may have entered by infiltration of sea-water from the surrounding ocean, or (2) through more or less deep-seated infiltration of water originally meteoric, or, finally, (3) that it may be considered strictly magmatic in character and an original constituent of the lava.

The volcanoes of Hawaii are completely surrounded at no great distance by the sea, which rises on their flanks to a height of 15,000 or 16,000 feet, according to charted soundings and the observations of Dutton.[23] The crater of Kilauea is about 15 miles from the nearest approach of sea-water, as recorded by the most modern surveys. The rock is for the most part porous in high degree. Above sealevel rain falls almost daily on the island up to elevations of 7,000 or 8,000 feet. Most of this meteoric water is deposited on the windward side[24] of the mountains and the leeward portions are desert or nearly so. The Kilauea crater is situated on the flank of Mauna Loa at an elevation of about 4,000 feet above the sea and is exactly on the ridge which separates the region of rainfall from the desert of Kau. It is somewhat misleading to assume with Dana that the rainfall at the crater is comparable with the rainfall at Hilo, the nearest considerable town where meteorologic observations are made. Hilo is to windward of the crater and at sealevel. At the Volcano House, still some 3 miles to windward of Halemaumau, the rainfall tables lately published by the United States Geological Survey give the annual average for the years 1909-1911 as 78.7 inches at the Volcano House and 136.5 inches at Hilo. It is also true, though it can not yet be supported by measured data, that the rainfall at Halemaumau is even smaller than that recorded at the Volcano House, for at an equal distance to leeward of Halemaumau the country is desert and practically without rainfall. The present crater lies in the midst of this transition zone from 78 inches to zero. Be that as it may, there is a more or less abundant rainfall at Kilauea, even though the aggregate amount is much smaller than has hitherto been supposed.

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[23] C. E. Dutton: Hawaiian volcanoes. Fourth Annual Report, U. S. Geological Survey, 1882-1883.

There is a further fact of observation which may be cited in this connection. Wells have been bored on the sugar plantations at elevations up to 2,000 feet on Hawaii and on the other islands. In these borings water is invariably met with (so far as we were able to learn) at sealevel only. The water is ordinarily fresh, but a heavy draft on it always has the effect of increasing its salt content, and some of the wells have been permanently ruined for irrigation purposes by this means.

So far as the conditions surrounding this volcano are concerned, therefore, water in some form would seem to be very widely distributed except on the high mountains, and as freely available as silica for active participation in any form of volcanic activity. In the present preliminary survey of the situation it therefore appears as if any attempt to assign the water found in the lava to one or other of these three conceivable sources, or perhaps better, to justify any specific distribution of it among the three conceivable sources, must be based on assumptions of a somewhat arbitrary and hypothetical character. Nevertheless, there are some indications which inevitably give direction to the probabilities which an individual observer may fix on. First and most important, in our opinion, is the fact that the nitrogen found in the emanation is free from argon. It is plain that if atmospheric water is to reach a hot lava column at a temperature of 1,000° or higher it must do so as a gas, and therefore on the same terms as other atmospheric gases. Argon is invariably contained in the air in measurable quantity and forms no chemical compounds. Whence it follows that if the gases of the atmosphere had reached the liquid lava in any manner whatsoever the argon would be released with the others, but no trace of argon was found.

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[24] It will, of course, be recalled that the islands of the Hawaiian group are within the trade-wind belt, and that the direction of the wind is very nearly constant throughout most of the year.

The second difficulty is to conceive a mechanism whereby atmospheric or surface water of whatever origin (for example, the sea) can make its way into a lava column or basin at a temperature of 1,000° or more. The Daubrée experiment, whereby water vapor was found to make its way through 2 centimeters of sandstone against an excess pressure within, though often quoted in this connection, does not help us to a solution of it. The force which was active in Daubrée's experiment is the surface tension of water only,[25] and water will obviously have no surface tension above its critical temperature of 374° (except perhaps in so far as salts in solution may have the effect of raising this critical temperature slightly). This temperature passed, water must make its way precisely like any

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[25] "Capillary forces are effective only when there is a surface of separation within the pores. . . . Since the pressure discontinuity occurs only at the *surface of separation*, a column of liquid can be supported *only when there is a free liquid surface within the capillary*. . . .

". . . As regards the influence of temperature on the surface tension of water, all the investigations unite in showing that its surface tension decreases regularly with rise of temperature, becoming zero, of course, at the critical temperature where there is no surface of separation. The relation is practically linear when the whole range is considered; it may be represented with sufficient accuracy by the formula,

$$\sigma_t = 78 - 0.21\ t \text{ or } 0.21\ (370 - t)$$

where σ_t is the surface tension at $t°$ (temperature centigrade) expressed in dynes per centimeter.

". . . From this . . . it is evident that the pressure producible by capillarity is insignificant in comparison with the hydrostatic pressure, except for very fine pores . . . and this minuteness of the pores leads us to inquire what amount of water could actually flow through them. . . . Assuming the mean viscosity of the water to be 0.005 (its value at a temperature of 30°), the amount of water flowing through a pore of diameter 1 μ (*i. e.*, 1/25000 inch) would be about 15×10^{-6} cc. per year. . . . Now, if we make the very generous estimate that 10 per cent of the volume occupied by the rock consists of pore spaces . . . the quantity of water flowing would be only 15 cc. per sq. cm. of surface per year. . . . If the diameter of the pores is 0.01 μ the amount of water flowing would be 0.0015 cc. per sq. cm. of surface per year. . . . In other words, a period of 1,000 years would be required for a quantity of water equivalent to 1.5 cms. (about one-half inch) of rain to flow past a given horizontal plane.

". . . It appears, therefore, as if the probabilities were all against the notion that appreciable amounts of meteoric water can ever penetrate into deep-seated and highly heated rock-masses." (John Johnston and L. H. Adams: "Observations on the Daubrée experiment and capillarity in relation to certain geologic speculations." Journal of Geology, vol. 22, in press, 1913.)

other gas by diffusion through pores or by overcoming whatever chemical or mechanical conditions it may encounter. The prospect is not an encouraging one. The hydrostatic pressure at great depths of the sea would appear to be the only sufficiently powerful agent to drive water against a high adverse temperature gradient, but to invoke this would be to invite nice distinctions of where "magmatic" water begins and "meteoric" water ends. The presence or absence of chlorine is not a conclusive factor one way or the other, because the physical processes of infiltration through porous rock and of distillation are alike of such a kind as gradually to leave the dissolved salts behind; this is illustrated by the fact that the bore-holes yield fresh water except when the infiltration is very rapid.

To us, therefore, such evidence as there is appears to indicate that the water released from the liquid lava when it reaches the surface is entitled to be considered an original component of the lava with as much right as the sulphur or the carbon.

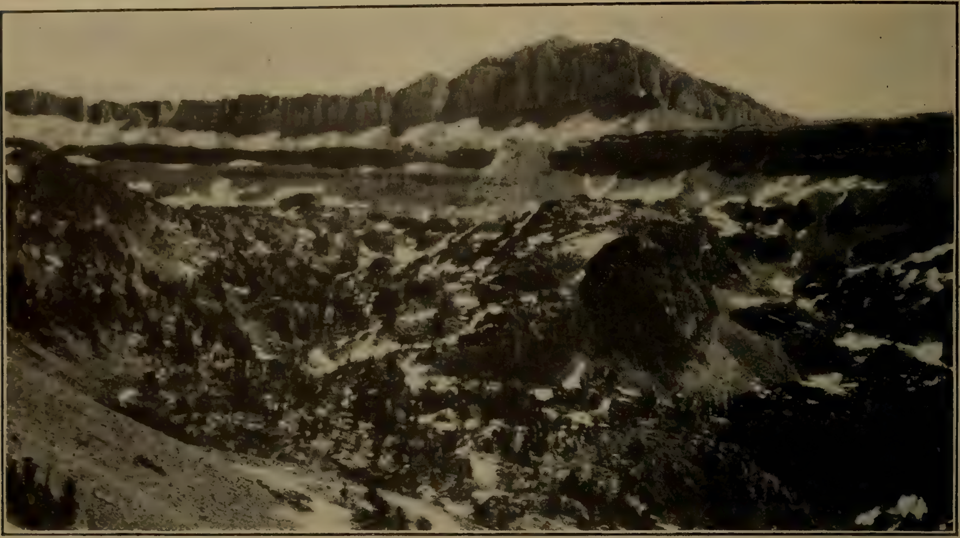

FIGURE 1.—SOUTHWEST SIDE OF DOUBLETOP MOUNTAIN IN THE GROS VENTRE RANGE

The cliff-making layer at the top is the Bighorn dolomite. It is underlain here by Cambrian shale and limestone and pre-Cambrian granitic rocks

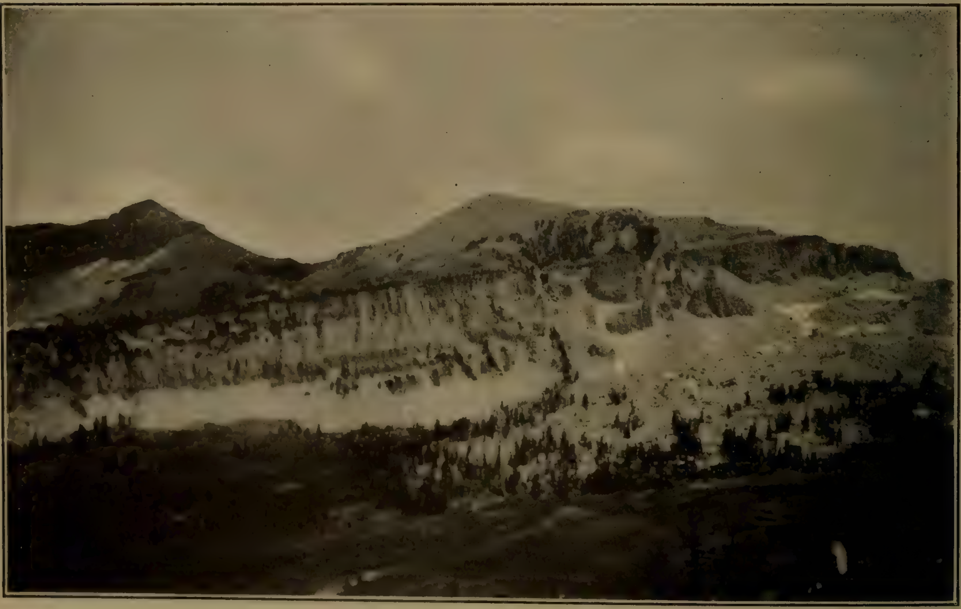

FIGURE 2.—WALL OF BIGHORN DOLOMITE

This wall is in the valley of Birch Creek near the north end of the Teton Range. The shaly Devonian beds and the Madison limestone are seen above and to the left

DOUBLETOP MOUNTAIN AND WALL OF BIGHORN DOLOMITE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 24, PP. 607-624, PLS. 28-35   DECEMBER 22, 1913
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

ORIGIN OF THE BIGHORN DOLOMITE OF WYOMING[1]

BY ELIOT BLACKWELDER

(Read before the Paleontological Society December 31, 1912)

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INTRODUCTION

TOPOGRAPHIC EXPRESSION

Among all the sedimentary formations in Wyoming there is probably none more persistently and fully exposed along its outcrops than the early Paleozoic dolomite, which Darton[2] has called the Bighorn limestone. So massive are its beds that in many places it seems to consist of but a single stratum 100 to 300 feet thick. By breaking off along vertical joints the formation leaves continuous and often impassable cliffs where the beds are not highly inclined, or rises in sharp "hogback" ridges where the dip is steep. Other Paleozoic terranes, such as the Madison limestone and the Tensleep sandstone, make cliffs and ridges, but none so uniform and persistent as the Bighorn dolomite. The individuality of its expo-

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[1] Published by permission of the Director of the U. S. Geological Survey. A preliminary digest of this paper was presented at the meeting of the Geological Society of America at New Haven in December, 1912. (See Bull. Geol. Soc. Am., vol. 24, 1913, p. 115.)

[2] N. H. Darton: Geology of the Bighorn Mountains of Wyoming. U. S. Geological Survey, Professional Paper No. 51, 1906.

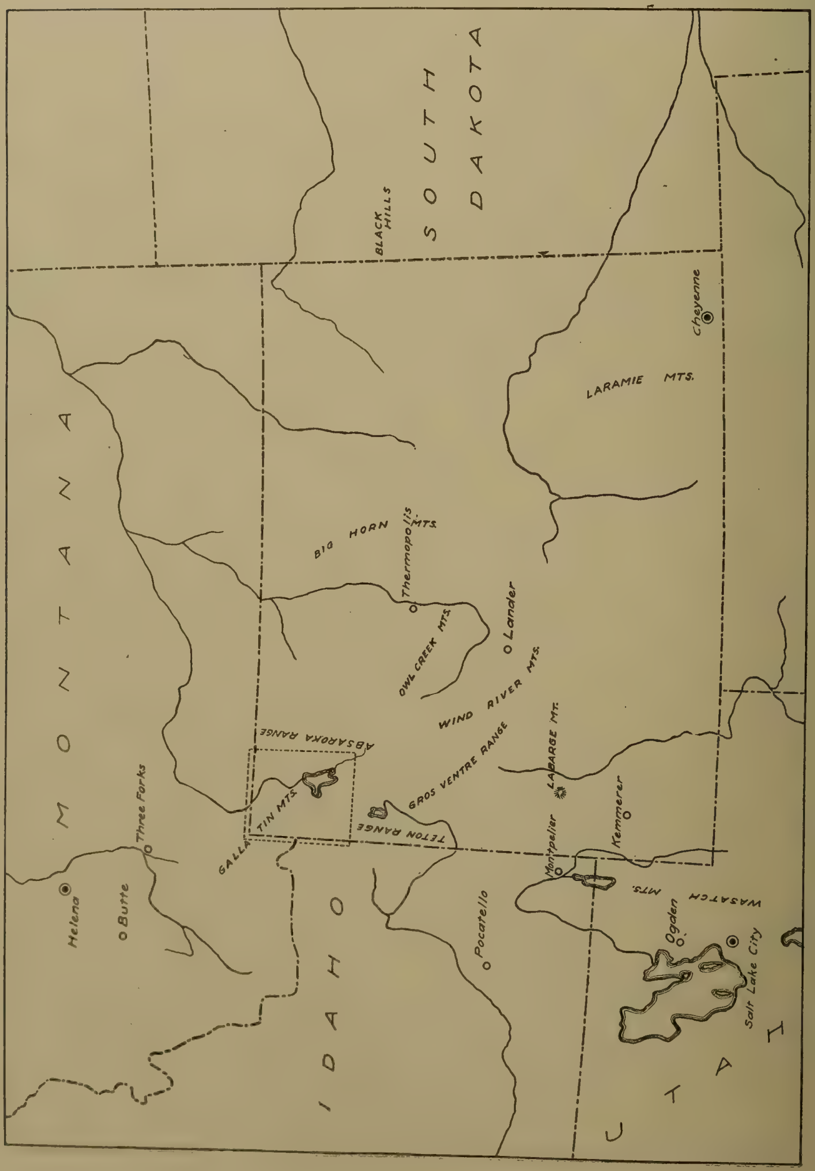
MONTANA
SOUTH DAKOTA
BLACK HILLS
IDAHO
UTAH
Helena
Butte
Three Forks
GALLATIN MTS.
ABSAROKA RANGE
TETON RANGE
GROS VENTRE RANGE
WIND RIVER MTS.
OWL CREEK MTS.
BIG HORN MTS.
Thermopolis
Lander
LABARGE MT.
Kemmerer
Montpelier
Pocatello
Ogden
Salt Lake City
WASATCH MTS.
LARAMIE MTS.
Cheyenne

FIGURE 1.—*Outline Map of the Region within which the Bighorn Dolomite has been Found*

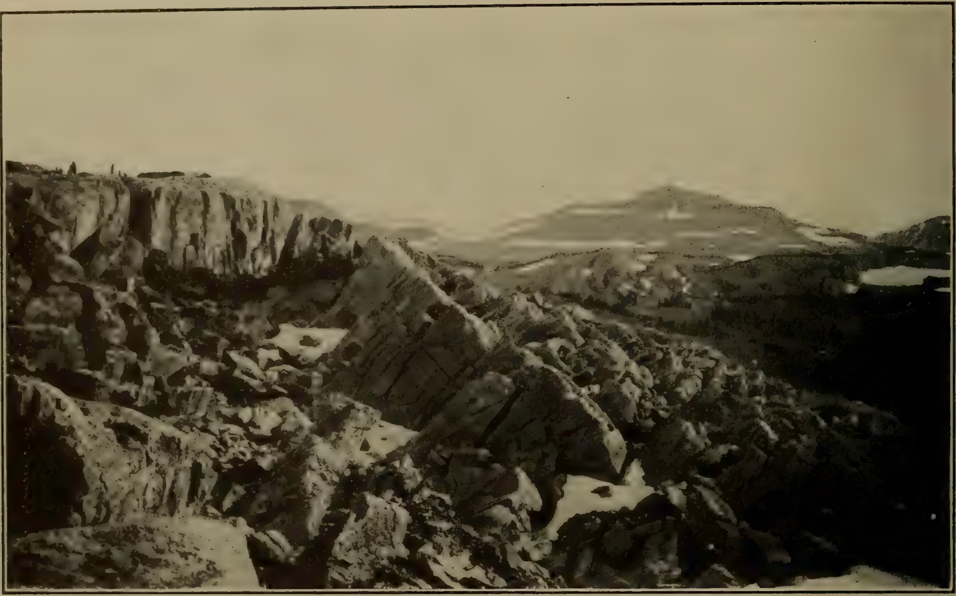

FIGURE 1.—A ROCK FALL IN THE BIGHORN DOLOMITE
This rock fall is near the head of the Gros Ventre River. Steamboat Peak in the distance

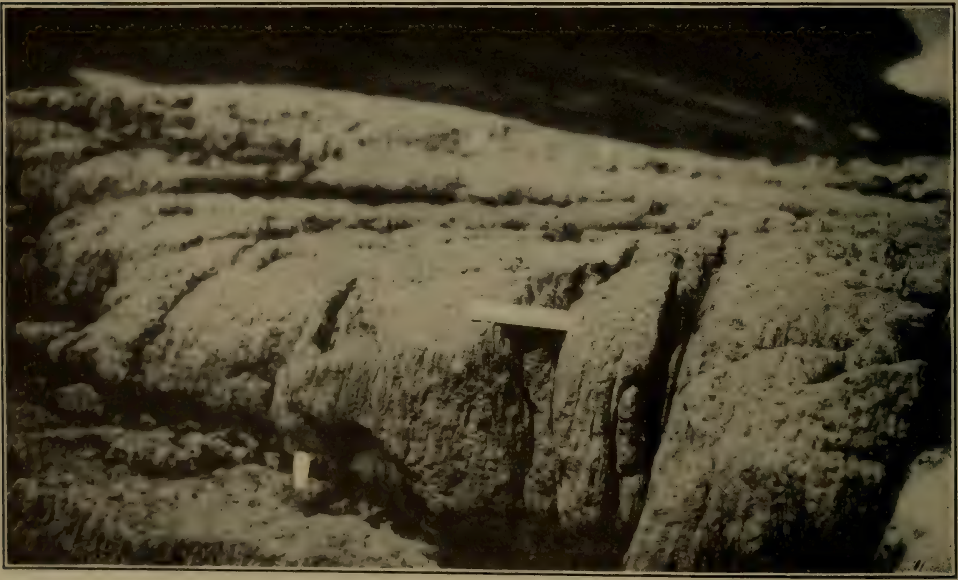

FIGURE 2.—GLACIATED OUTCROP OF THE BIGHORN DOLOMITE
Showing the corrugated upright structures interpreted as the remains of calcareous algæ. The ruler is 6 inches long. Head of Dry Creek in the Gros Ventre Range

BIGHORN DOLOMITE

sures is such that by one sufficiently acquainted with its peculiarities the outcrops may be recognized miles away.

DISTRIBUTION

In the type locality, on the east slope of the Bighorn Range, the Bighorn "limestone" is a massive light-colored dolomite about 300 feet thick. To the east, in the Black Hills of South Dakota, the Whitewood "limestone," first described by Jaggar[3] and afterward by Darton and others, has the typical characteristics of the Bighorn formation and contains very similar fossils. Westward, as noted by Darton,[4] the dolomite has been recognized in the Owl Creek, Wind River, Absaroka, Gros Ventre, and Teton ranges. In most of these exposures it is about 300 feet thick, although in the vicinity of the Wind River basin it dwindles to 150 and locally even to less than 100 feet. It disappears entirely in southeastern Wyoming. To the southwest, however, I have recognized the formation by its distinctly lithologic character in Labarge Mountain, 40 miles north of Kemmerer, Wyoming. It is there at least 150 feet thick and perhaps more. In the northern part of the Wasatch Range near Brigham, Utah, an extremely massive white dolomite occupies approximately the position of the Bighorn and has many of its characteristics. It is several hundred feet thick, but has not yet been adequately studied. Published descriptions[5] of the rocks in southwestern Montana and Yellowstone Park strongly suggest that the Bighorn dolomite is represented there as a part of the Jefferson limestone of Peale, and that it may be essentially the equivalent of the Jefferson limestone of Hague, Weed, and others. Farther extensions into Colorado on the south are discussed by Darton,[6] and others into central Utah, and even Nevada on the west might be suggested if correlation were the primary purpose of this paper.

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[3] T. A. Jaggar, Jr.: Economic resources of the northern Black Hills. U. S. Geological Survey, Professional Paper No. 26, 1904, p. 16.

[4] N. H. Darton: Fish remains in Ordovician rocks in Bighorn Mountains, Wyoming, with a résumé of Ordovician geology of the Northwest. Bull. Geol. Soc. Am., vol. 17, 1906, pp. 554-556.

[5] Hague, Iddings, and Weed: Descriptive geology of Yellowstone Park. U. S. Geological Survey, Monograph XXXII, pt. 2, 1899; Absaroka Folio, Geological Atlas of the United States, No. 52, 1899; Yellowstone Park Folio, Geological Atlas of the United States, No. 30, 1896.

A. C. Peale: Paleozoic section at Three Forks, Montana. U. S. Geological Survey, Bull. 110, 1893.

W. H. Weed and L. V. Pirsson: Geology of Castle Mountain Mining District. U. S. Geological Survey, Bull. 139, 1896; Geology of Little Rocky Mountains, Journal of Geology, vol. iv, 1896, pp. 399-428.

W. H. Weed: Geology of Little Belt Mountains, Montana. U. S. Geological Survey, 20th Ann. Rept., pt. iii, 1900, pp. 287-289.

[6] Loc. cit.

GEOLOGIC AGE

Early students[7] of the Wyoming geologic formations referred the Bighorn dolomite to the Niagaran epoch on the basis of a few corals, such as *Halysites catenulatus,* which were then believed to indicate Silurian age.

In connection with the work of Darton in north-central Wyoming Ulrich[8] has studied the Bighorn fauna, meager though it is, and has concluded that it is all of Ordovician age, according to current usage by which the Richmond is assigned to the Ordovician period, but that several of the eastern horizons, including the Lower Trenton and the Richmond, are represented. Other collections from the Wind River, Gros Ventre, and Teton ranges have lately been submitted by me to Mr. Ulrich and all have been referred to the Ordovician.

On the other hand, I recently found in the Gros Ventre Range, in rocks which I confidently refer to the Bighorn, a small collection of fossils containing not only the usual corals and fragmentary brachiopods and mollusks, but also several species of trilobites. This faunule is referred to the Richmond fauna by Mr. Ulrich, but in the estimation of both Dr. Kindle and Dr. Stuart Weller it is of Niagaran age. In view of this apparent conflict of evidence and the disagreement among the students of the faunas, the age limits of the Bighorn must for the present be considered unsettled.

GENERAL CHARACTERISTICS

The massive ledges and the huge talus blocks which in most cases have fallen from them generally afford plenty of opportunity for examining the character of the Bighorn dolomite. A first inspection is sufficient to impress one with the unusual roughness of its weathered surface, a feature which has been repeatedly described by Darton and others. In successive beds there is considerable variety in the pattern, as an inspection of plates 29-33 will serve to show. One of the commonest phases in eastern Wyoming shows a network of raised welts about half an inch wide (see plate 33 and illustrations in Darton's papers). Many other ledges are covered with roughly conical projections which have waxy dark brown points, contrasting with the dense cream-colored matrix surrounding them. Again, the surface may be covered with branching stalklike fea-

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[7] Orestes St. John: Hayden Survey. Ann. Rept., vol. xi, 1877, and vol. xii, 1878.
J. B. Comstock: Expedition to Rocky Mountains and Yellowstone Park, U. S. Army Engineers, 1873.

[8] N. H. Darton: Geology of the Bighorn Mountains of Wyoming. U. S. Geological Survey, Professional Paper No. 51, 1906, pp. 28-29.

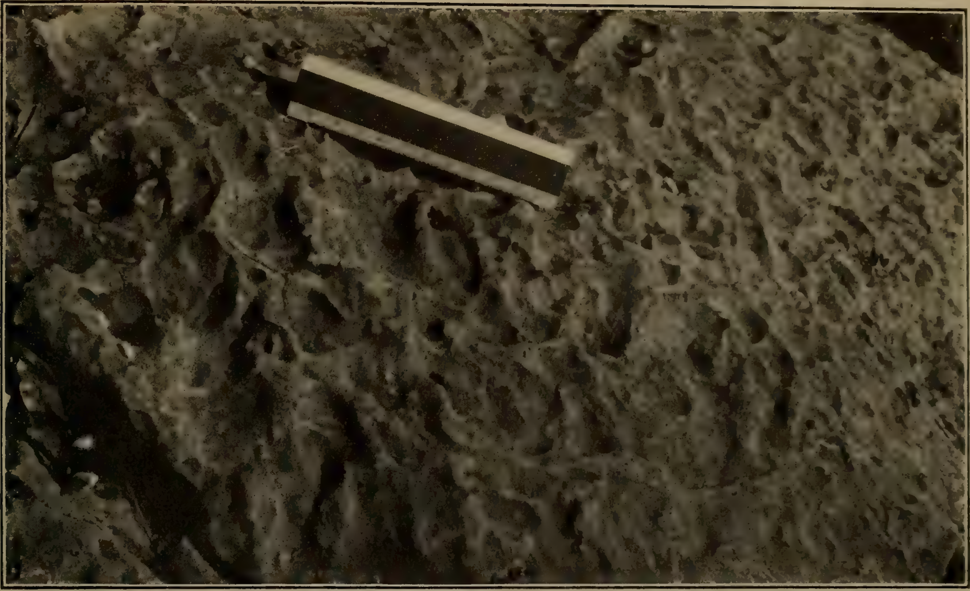

FIGURE 1.—A DETAIL OF THE ROUGH SURFACE OF THE BIGHORN DOLOMITE

Showing the raised welts and points and also the fossil-like inclusions. Darby Creek in the Teton Range

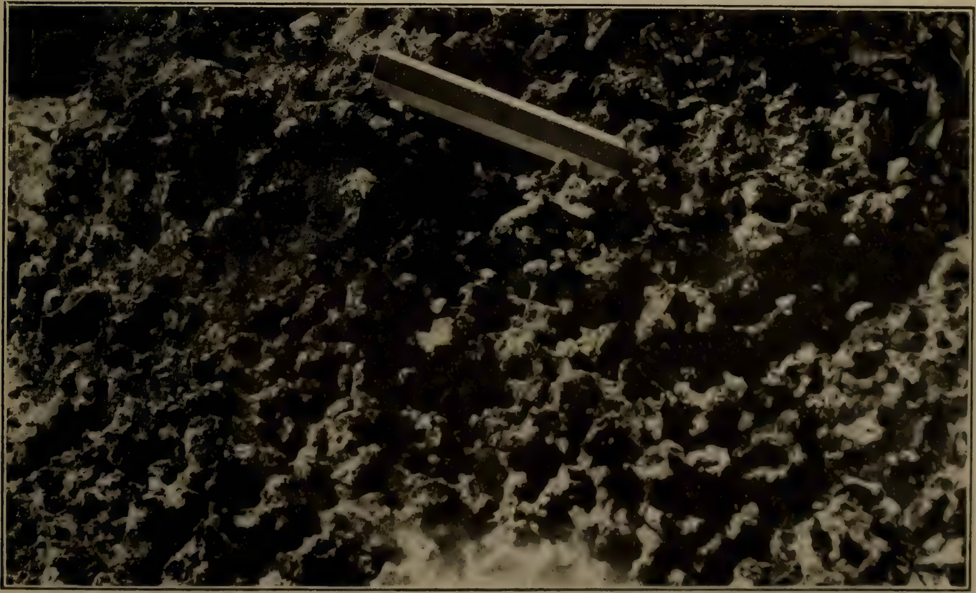

FIGURE 2.—A DETAIL OF THE ROUGHEST PHASE OF THE WEATHERED SURFACE OF THE BIGHORN DOLOMITE

The locality is on Darby Creek in the Teton Range

BIGHORN DOLOMITE

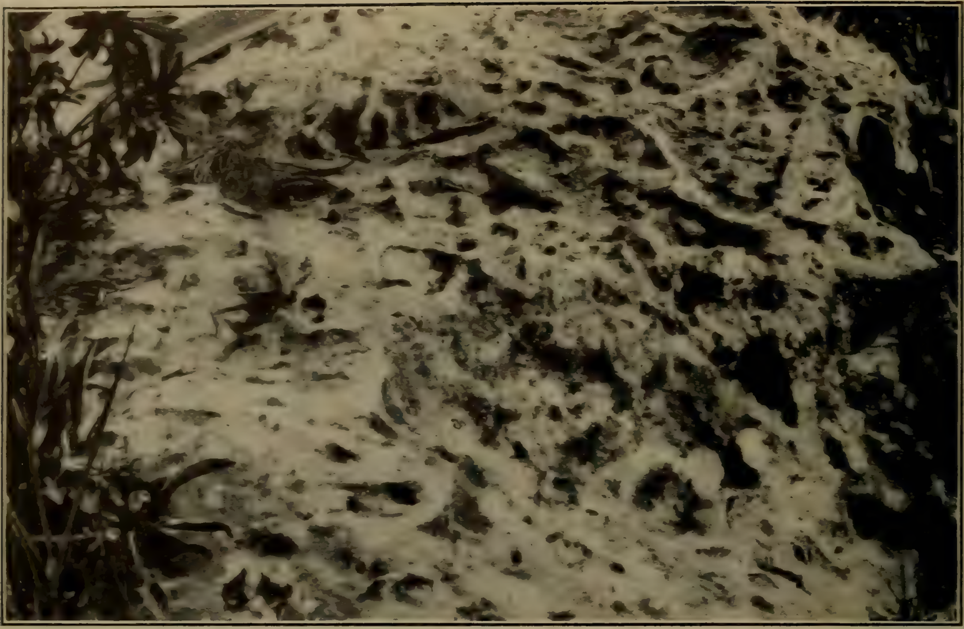

Figure 1.—A Detail of the weathered Surface of the Bighorn Dolomite
Showing a branching alga (?) weathered out in relief. Darby Creek in the Teton Range

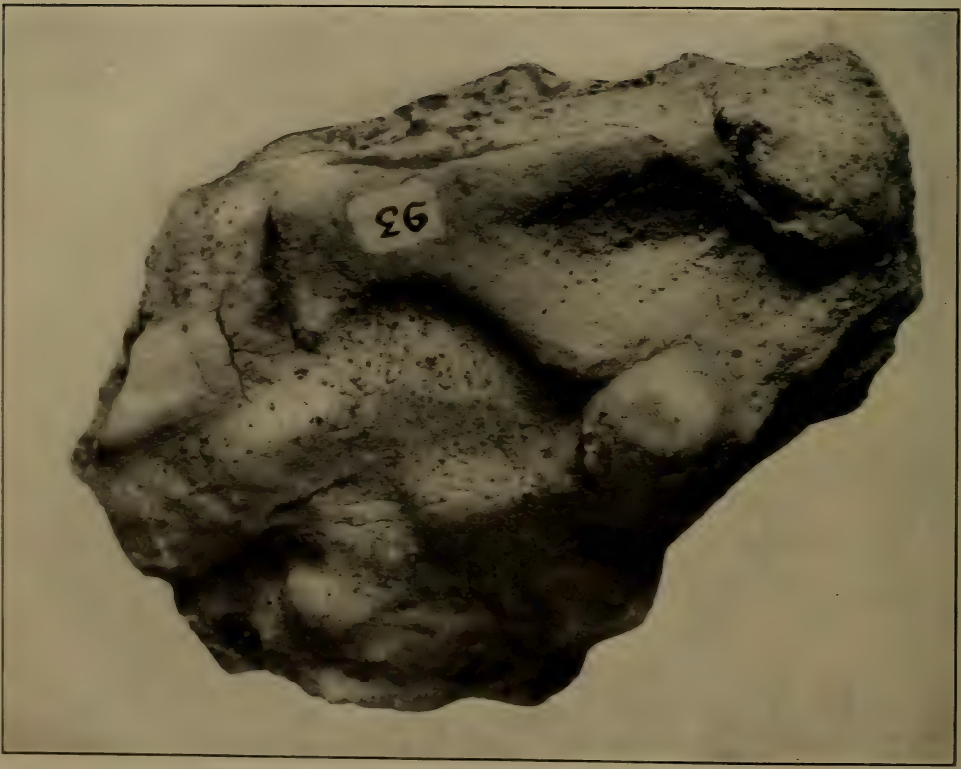

Figure 2.—A branching Welt suggesting algal Origin
Teton Canyon, Teton Range

BIGHORN DOLOMITE

tures which weather out in strong relief (plate 31). Somewhat less common surface features are disk-shaped bodies of porcelain-like material, embossed on a coarser ground-mass (plate 32, figure 2). In the lower part of the formation, especially in the Teton and Gros Ventre ranges, there are beds which show wavy horizontal lamination, more or less suggestive of stromatoporoid growths.

By examining the weathered surface (plate 30) as it generally appears, with its sharp projecting points or raised welts one-half inch or more in breadth, one may see that the projections and ridges correspond to a slightly darker material within the rock itself. This dark material is distributed in sinuous upright or prostrate rods or corrugated sheets or in thick branching stemlike structures. In many specimens these darker structures are dull smoky gray, while the surrounding material is cream-colored or white. It is also a noteworthy fact that the texture of the darker parts is very dense, while that of the lighter parts is coarser, as well as more porous. It is important to remark, however, that all of these bodies have vague, indefinite outlines. The dark structures are nearly uniform in texture and composition, but the matrix is a medley of particles of various sizes, including bits of recognizable fossils.

The prevailing color of the Bighorn outcrops is cream-colored to grayish white. Some beds are more or less mottled with grayish brown and in places the rock is slightly stained pink by oxides of iron. Freshly broken surfaces are generally more distinctly gray and are obscurely mottled with darker gray, as noted above. Dark brown and blackish dolomite, which are common in the overlying Devonian strata, are conspicuously absent from the Bighorn. Colors also aid in distinguishing it from the underlying Cambrian beds, because it lacks the red and ocherous lenses and stripes which are characteristic of the older limestones in Wyoming.

When freshly broken, the Bighorn rock usually emits a distinct but not strong odor of petroleum or hydrogen sulphide, presumably due to residual material from the decay of organic tissues.

Unlike many dolomites, the Bighorn contains but little siliceous matter. In the lower layers there are generally thin, irregular lenses and laminæ of white or cream-colored chert, and locally a few round chert nodules have been seen at higher horizons.

Of the chemical analyses which have been made from the Bighorn formation all show a comparatively pure dolomite. The following table gives analyses made in the laboratory of the United States Geological Survey:

Partial Analyses of Dolomites from the Bighorn Formation

	1	2	3	4	5	6	7
SiO_2	2.30	......	......	......	......	......	.0
Al_2O_3 and Fe_2O_3	1.50	......	.22	trace	......	......	.0
Insoluble in dilute HCl	(3.80)	4.67	.53	.35	.42	1.99	.0
CaO	29.35	30.14	31.17	30.62	30.43	30.34	30.4
MgO	20.19	18.41	20.76	20.32	20.85	20.10	21.9
CO_2	45.00	44.24	47.75*	46.92*	47.10*	46.30*	47.7
Undetermined	1.06	2.54*	.00*	1.79*	1.20*	1.32*	.0
Total	100.00	100.00	100.43	100.00	100.00	100.05	100.00

1. Massive cream-colored dolomite, Bull Lake, Wind River Range. Analyst, J. G. Fairchild.
2. Thin-bedded gray dolomite of fossiliferous zone, Doubletop Peak, Gros Ventre Range. Analyst, C. Palmer.
3. Massive cream-colored dolomite, Labarge Mountain, Green River Valley. Analyst, J. G. Fairchild.
4. Massive gray dolomite, Shoal Creek (upper falls), Gros Ventre Range. Analyst, J. G. Fairchild.
5. Massive gray mottled dolomite, Leigh Creek, Teton Range. Analyst, W. C. Wheeler.
6. Average of analyses, 1-5.
7. Ideal composition of dolomite.

Under the microscope the rock appears to consist almost entirely of carbonate crystals, which, of course, must either be those of the mineral dolomite or a mixture of calcite and magnesite. Microchemical tests indicate dolomite only. In a single instance a minute cavity was found to be filled with chalcedonic quartz, and in some specimens the interstices between the dolomite crystals contain dustlike particles of red ferruginous matter which gives the rock the pinkish tinge occasionally noted. It is significant that in all the specimens examined under the microscope not a single sand grain has been seen, and particles of any kind, other than the carbonates, are very rare.

Texturally the rock shows considerable variety: some parts are fine grained, some moderately coarse, and still others contain rather large particles imbedded in a fine-grained mass. The darker parts consist of very small, tightly interlocking crystals of dolomite averaging about .05 millimeter in diameter. The lighter portions of the rock which inclose the dark bodies are decidedly coarser and also more variable in texture. The average diameter of the crystals here is about .10 to .16 millimeter, but many are less than .05 millimeter and others more than .3 milli-

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* Calculated.

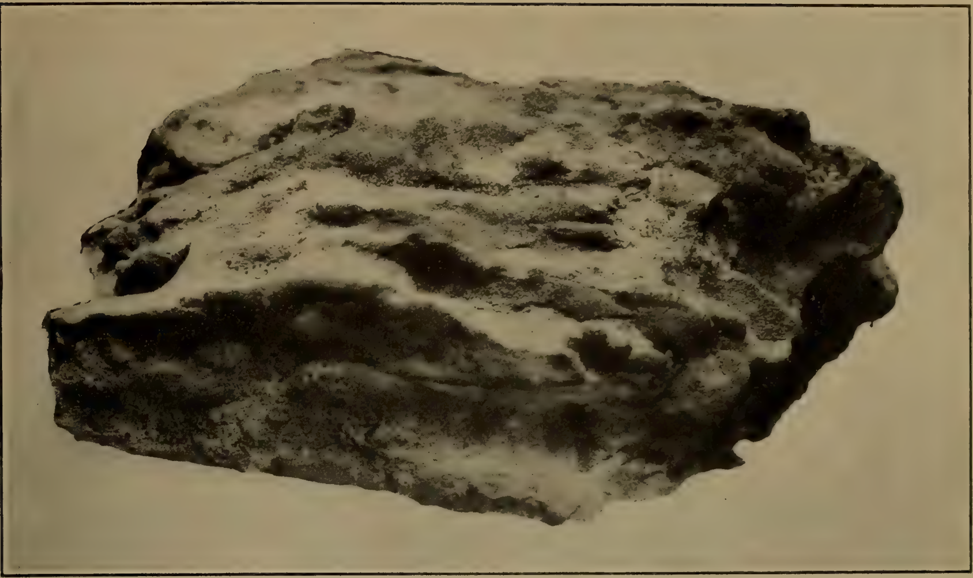

Figure 1.—Weathered Specimen of the Bighorn Dolomite

Showing the relation between the transverse fluting and the pitted surface. Gros Ventre Range

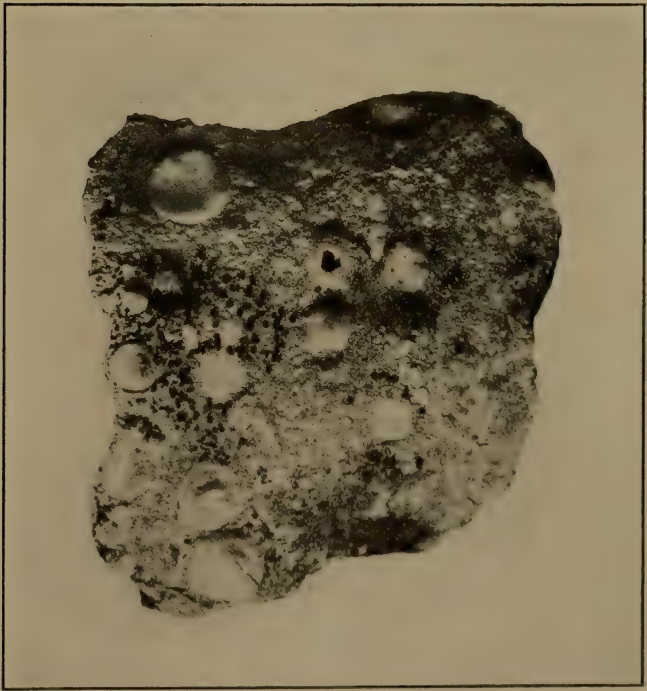

Figure 2.—A somewhat unusual Phase of the Bighorn Dolomite

In this specimen the small disk-shaped bodies may represent algæ of another type. Teton Range

BIGHORN DOLOMITE

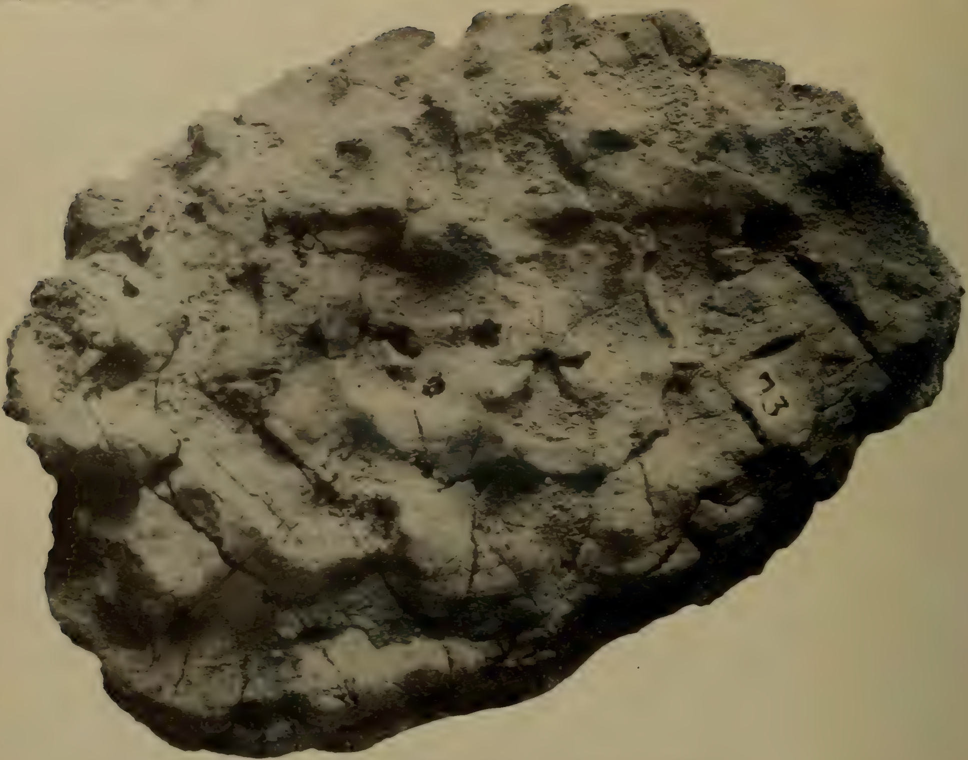

FIGURE 1.—WEATHERED BLOCK OF BIGHORN DOLOMITE

Showing broad, raised welts in a rude network, the interstices of which are filled with miscellaneous fragments of fossils. From Birdseye, south of Thermopolis, Wyoming

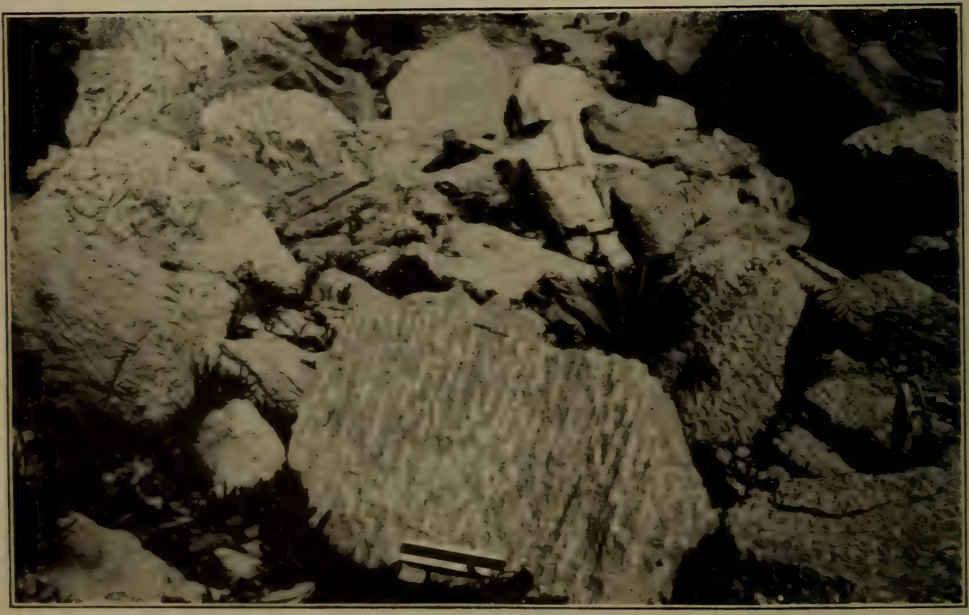

FIGURE 2.—TALUS FROM THE BIGHORN DOLOMITE

Several blocks to the right show the deeply pitted surface. The block in the central foreground shows the irregular branching growths in upright position with reference to the bedding. **North Fork of Teton River, Teton Range.**

BIGHORN DOLOMITE

meter thick. In these coarser-grained portions there are also roundish bodies and others of more or less irregular shape, most of which consist of a single shapeless crystal of dolomite of abnormal size. They were probably segments of crinoid or cystid columns and bits of shells; but very few are now distinctly recognizable, because their outlines and internal structures have been obliterated by recrystallization. It is significant that these bits of fossils occur only in the coarse-grained matrix and not in the dark bodies.

That the Bighorn dolomite contains fossils is well known, for traces of them may be observed on the weathered outcrops of almost any of the beds, although almost never well preserved and generally scarce. The commoner kinds are such corals as *Streptelasma, Halysites,* and *Favosites;* crinoid or cystid segments and unrecognizable brachiopods. These fossils are very rarely visible on freshly broken surfaces, and they appear on weathered faces only by virtue of the fact that they consist of large crystals which are less rapidly dissolved than the finer grains.

At both top and bottom the Bighorn is generally limited by disconformities—irregular cavernous contacts along which the dolomite is abruptly set off from the adjacent formations. In some exposures these contacts are marked by fragmental material apparently derived from the subjacent terrane and imbedded in a dolomite matrix. Generally the fragments are not distinctly water-worn and there is a conspicuous absence of quartz sand. At various horizons within the formation thin cross-bedded layers of cream-colored calcarenyte[9] occur, now somewhat altered by crystallization. These beds, evidently affected by currents, are noteworthy because they resemble the porous cream-colored matrix of many of the more massive beds. Even in the calcarenyte the microscope shows no foreign matter whatever.

INTERPRETATION

GENERAL SIGNIFICANCE

It is doubtless unnecessary to argue that the Bighorn dolomite is marine. If any specific evidence were required, the wide distribution of corals throughout its mass would be sufficient.[10] That it also represents deposition far from land is strongly suggested by the absence of recognizable clastic debris. It could hardly be purer if it had been deposited in mid-ocean.

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[9] A rock consisting of sandlike calcareous particles cemented (Grabau).

[10] Weller has recently called attention to the fact that the fossils in most dolomites, such as the Niagara, Galena, and Knox of the Eastern States, are essentially like those of ordinary marine limestones. (Bull. Geol. Soc. Am., vol. 22, 1911, p. 231.)

The question as to depth of water is less readily answered. The prevalence of corals suggests shallow or at least moderate depths, but the evidence loses something of its cogency when we consider that the predominant corals are of the solitary types, or such compound forms as grow in small isolated colonies rather than in reefs. If, as suggested in later pages, the peculiar structures of the Bighorn dolomite have been built by marine algæ of the bank-forming habit, then we have some reason to think that the depth of the sea was less than 120 meters. The modern colonial algæ have a greater bathymetric range than reef corals, but live only within the zone of effective light transmission. The occasional beds of cross-laminated calcarenyte seem to show plainly the action of currents strong enough to move and assort sandlike material. This also indicates a depth of less than 100 meters. Taken together these considerations seem to justify the inference that the Bighorn dolomite was deposited in continental rather than abysmal waters.

The conditions of temperature and salinity and the character of the marine solution can hardly be discussed with profit under present circumstances, although they were doubtless of the highest importance in determining the character of the formation.

ORIGIN OF THE STRUCTURES

The ill-defined but none the less existent branching structures with which most layers of the Bighorn dolomite are filled, and which express themselves on freshly broken surfaces as vague color-mottling and on weathered outcrops as alternating pits and ridges, have never been satisfactorily explained. Weed[11] notes that the darker portions owe their color and fetid odor to nitrogenous matter, but makes no further suggestion. Darton[12] ascribes the peculiarities of the weathered surface to a network of siliceous matter imbedded in the rock. To quote:

> "The massive limestone which constitutes the greater part of the formation is a rock usually of light buff color, somewhat darker when weathered, filled with a coarse mat or network of irregular, siliceous masses, mostly from one-half to one inch in diameter. On weathering, this siliceous material stands out a half inch or more on the rock surface as a ragged network, the purer rock between having been dissolved. . . . This feature and the very massive bedding are characteristic."

The origin of the supposed siliceous network is not discussed. As a whole Darton's explanation seems to be untenable, because the chemical analyses

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[11] W. H. Weed: Geology of the Little Belt Mountains, Montana. U. S. Geological Survey, 20th Ann. Rept., pt. iii, 1900, pp. 271-461.

[12] N. H. Darton: Fish remains in Ordovician rocks in Bighorn Mountains, Wyoming. Bull. Geol. Soc. Am., vol. 17, 1906, pp. 541-566.

(given on page 612) show that the characteristic rough weathering dolomite from several widely separated localities is a relatively pure rock containing in no case more than 2½ per cent of difficultly soluble matter, such as silica, and in some instancees hardly a trace. Moreover, thin sections when examined under the microscope would quickly show any network of siliceous material such as Darton supposed to be the cause. It seems to be true, however, that the pitted and ribbed surfaces are due to differential weathering, although the latter has probably been induced by differences in texture and porosity rather than in chemical composition. The very dense, fine-grained parts exclude dissolving solutions and by their strong internal cohesion resist the abrasive action of the wind—which in Wyoming is a major factor in rock wastage—while the more porous, coarser-grained cement more readily admits carbonated waters and its friable nature renders it more easily abradable. Etching tests with hydrochloric acid on polished surfaces of typical specimens of the rock show that the fine-grained parts are attacked much less rapidly than the coarser parts. After several hours the process actually produced a surface on which the dark dense bodies stood out with a relief of about half a millimeter. We may now seek an explanation of the observed textural differences.

In the absence of definitely recognizable organic structures, there may be reasonable doubt as to whether the branching, ill-defined masses are really of organic origin or not. The fact pointed out by Weed, that the problematical bodies are darkened by nitrogenous matter which is largely absent from the surrounding matrix, strongly suggests that the organic material is residual and once formed a part of the bodies themselves. A still more suggestive fact is the dichotomous habit of branching, which is repeated *ad infinitum* among these structures in successive outcrops. This and other matters of form are more or less significant of colonial organisms, and particularly of certain types of corals and calcareous algæ. It is an unfortunate fact, however, that no trace of definite internal structure now remains.

If the growths are in fact organic, what kind of organisms do they represent? The great branching intergrown masses suggest that inquiry be limited to the plantlike colonial types—among the animals the sponges, corals, and bryozoans, and among the plants some of the calcareous algæ. If they were siliceous sponges, we might reasonably expect to find spicules or a spicular network of chalcedonic quartz. The calcareous sponges have the requisite chemical composition, but none that are known, either in the modern or in the fossil state, seem to resemble in form the dark bodies in the Bighorn dolomite, nor do they now build massive banks comparable in their vast extent to those of the problematical organism of the Bighorn. It is difficult to believe that the obscure growths are coralline, inasmuch as the rock contains many corals and in all of them the characteristic structures are still distinct, although now seriously blurred by recrystallization. These more or less well-preserved corals have been found imbedded in the cement among the problematical growths throughout the Bighorn formation. The appearance and state of preservation of the coral structures is notably unlike that of the dark problematical bodies which are the subject of this inquiry. The bryozoans also seem unsuited to fit the demands of the case, partly because in most rocks they are preserved with more or less well-defined structural details and partly also because they are usually small, delicate, and measurably independent, whereas the Bighorn growths are thick, coarse bodies and evidently existed in enormous masses. On the whole no group of animals seems fitted to serve the needs of the case in a satisfactory way, although they are not positively excluded by the available evidence.

An examination of the calcareous algæ from the same viewpoint leads to more favorable results. Although the majority of marine algæ contain no hard parts whatever, there are many which are either incrusted with lime carbonate or secrete solid stony masses comparable to those made by the reef-building corals. Among the modern calcareous algæ a few contain lime carbonate in the form of aragonite, whereas in the others the mineral is calcite. Although these two minerals are apparently identical in chemical composition, they have sufficiently different physical properties that it becomes important to discriminate between them. Thus aragonite is more soluble than calcite, is more readily altered, has a higher specific gravity, poorer cleavage, and a different electrical potential.

According to Engler and Prantl,[13] the calcareous algæ belong principally to three great classes: the blue-green algæ (*Chlorophyceæ*), the Stoneworts (*Characeæ*), and the red algæ (*Rhodophyceæ*).

Among the blue-green algæ several genera of the *Dasycladaceæ* and *Codiaceæ* have more or less calcified or incrusted thalli. The typical genus *Codium* assumes a cylindrical stalklike form with many branches, but is not calcified. In the Bighorn dolomite there are branching growths which bear an external resemblance to *Codium,* although there is no positive evidence that the two are related. *Halimeda,* one of the best known and most abundant of the calcified blue-green algæ in modern seas, consists of loosely articulated fan-shaped segments incrusted with aragonite. No forms observed in the Bighorn dolomite are directly suggestive of this genus. Indeed it is not clear that after the decomposition of the proto-

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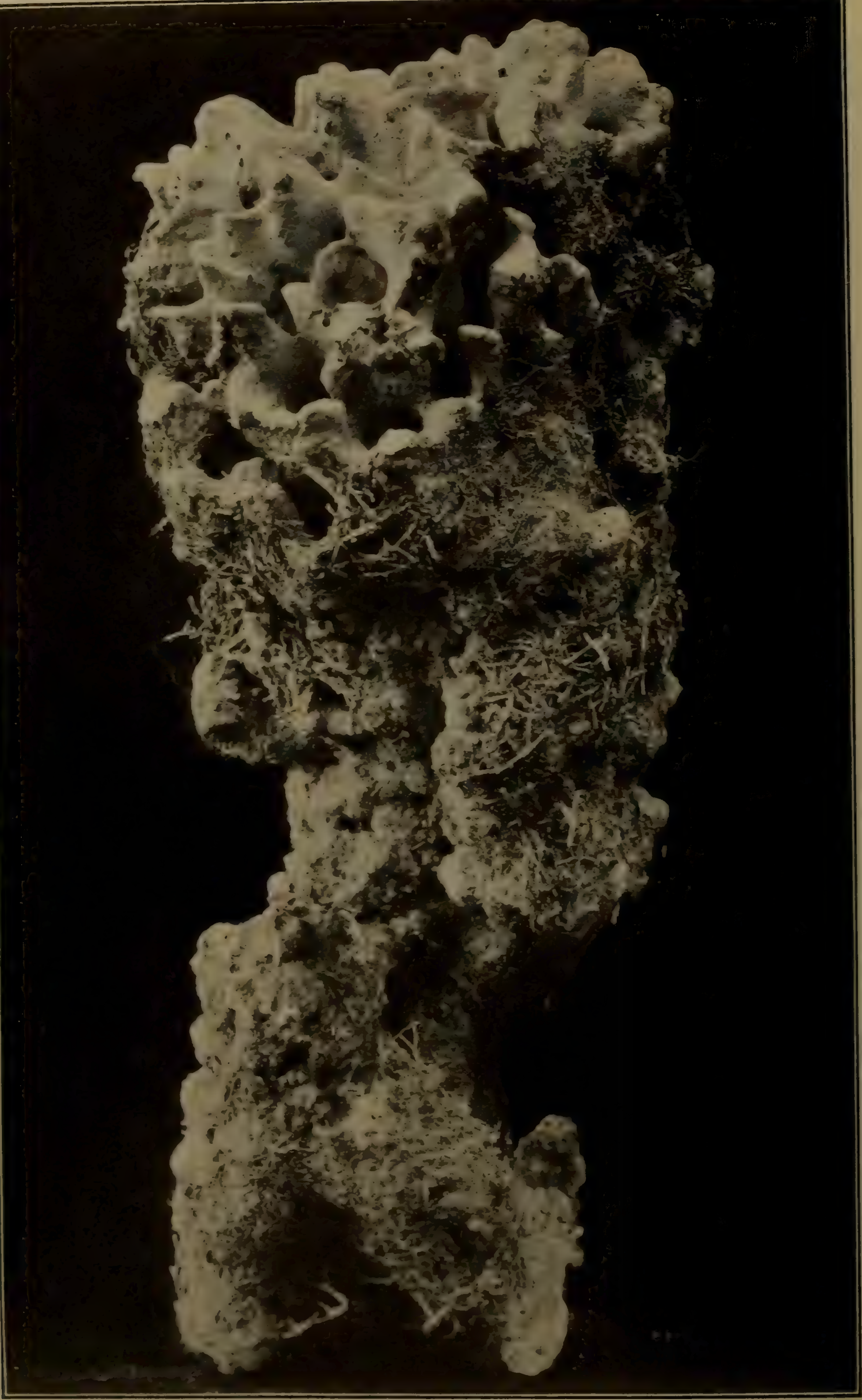
[13] **Die Natürlichen Pflanzenfamilien, Teil 1, Abteilung 2, 1897.**



A FRAGMENT OF A MODERN STONY COLONY OF CALCAREOUS ALGÆ (LITHOPHYLLUM ANTILLARUM, FOSLIE AND HOWE)

This specimen from Porto Rico is about 8 inches high and is partly incrusted with more delicate algæ of other species. Reproduced through the courtesy of Dr. Marshall A. Howe, New York Botanical Garden plasmic thallus the calcareous matter would preserve its distinctive form; it might rather disintegrate and settle as a limy mud such as the stoneworts (*Chara*) produce.

The lime-secreting types of the red algæ nearly all belong to the well known family of "corallines" (*Corallinaceæ*), often called "nullipores," which form stony skeletons of calcite in great variety of form and size. Although most abundant in the tropics, they are widely distributed through all modern seas and range even into polar waters. Kjellman[14] reports that "numerous large banks of algæ are to be found in the arctic as well as in the temperate zone, although the number of species is less. Thus on the coast of Spitzbergen and Novaya Zemlya *Lithothamnion glaciale* covers the bottom in deep layers for several miles, and altogether determines the general aspect of the vegetation wherever it occurs. In the formation of future strata of the earth's crust in this region it must become of essential importance." Again Foslie states: "North of the polar circle on the coast of Norway banks have been met with which cover the bottom for several miles, and the plants appear in immense masses, frequently representing only one species." With the corals they often build massive reefs in shallow water, as observed by Howe[15] on the coast of Porto Rico, but according to Berthold[16] they are at their best in somewhat deeper water down to 100 to 120 meters (300 to 360 feet). There they grow in dense array, covering the bottom of the sea over considerable areas.

Corallina, one of the best known genera, assumes the form of rather delicate jointed filaments, with long slender branches. There is nothing about it resembling the structures which characterize the Bighorn dolomite. The genus *Lithothamnion* and several others form crusts on the surfaces of shells, corals, or rocks, and there are others which grow in isolated masses of various shapes. In the genus *Lithophyllum* several of the known species are particularly suggestive in this connection because they grow upward in the form of corrugated masses as solid and stony as those of any coral. The colonies are traversed by parallel sinuous tubes, about half an inch in diameter, and these tubes become in time filled with miscellaneous calcareous debris from the many kinds of organisms that inhabit reefs. Specimens of *Lithophyllum antillarum* (see plate 34) recently collected by Dr. Marshall A. Howe, of the New York Botanical Garden, exhibit forms and a habit of growth which strongly suggest, when due allowance is made for complete cementation and subsequent alteration, the structures we now find in the Bighorn dolomite. Even the little winding tubes with which the Bighorn growths are perforated here and there suggest the galleries of boring organisms which today rarely leave reef structures of any kind undamaged. Also the variety of forms visible in the Bighorn growths seems to parallel the wealth of species and facies of the modern corallines as they have been observed in tropical seas.

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[14] Quoted by M. Foslie in "Fauna and Geography of the Maldive and Laccadive archipelagos," by Gardner, 1903, p. 462.

[15] M. A. Howe: Bulletin Torrey Botanical Club, vol. 33, 1906, pp. 577-580.

[16] Quoted by A. Agassiz: "Three Cruises of the Blake," vol. 1, p. 312.

Since the positive identification of algæ depends almost entirely on the recognition of their delicate, cellular structures under the microscope, it is unlikely that the problematical growths of the Bighorn terrane can ever be satisfactorily recognized, inasmuch as nearly all traces of original organic structures have been obliterated. The cells of the modern algæ, such as *Lithophyllum,* average about .01 millimeter in diameter, but the Bighorn rock is crystallized in grains .05 to .10 millimeter in diameter. Under these circumstances we ought not to expect to find the algal cells preserved.

This disappearance of minute structures, one of the inevitable results of the process of crystallization, may well explain the fact that marine algæ, although often reported from Paleozoic limestones, have in perhaps no instance been satisfactorily identified from internal cell characters. As a lowly and hence doubtless primitive group the antiquity of the algæ may be supposed to be great. We have therefore some *a priori* reason to believe that they were well differentiated and abundant in very remote geological periods, and also that the modern families are of relatively ancient lineage.

These facts have been discussed in some detail in order to show that the modern coralline algæ seem to fill the requirements of the case for the Bighorn dolomite in that they are varied in form, grow in banks of great extent and generally of singular uniformity, and that they are less subject to limitations of depth and temperature than the corals. Possible objections on the ground of the absence of cellular structure or deficient paleontological evidence that algæ were abundant early in the Paleozoic era seem to be met by satisfactory explanations. Therefore it appears to me probable that the peculiar structures of the Bighorn dolomite are of organic origin, and that the more massive coralline algæ, such as the modern genus *Lithophyllum,* may fairly be regarded as competent to make such structures, if indeed they are not the only organisms which could have done so.

WHY THE ROCK IS A DOLOMITE

The magnesian composition of such formations as the Bighorn dolomite has apparently not yet been explained in such a manner as to be fully

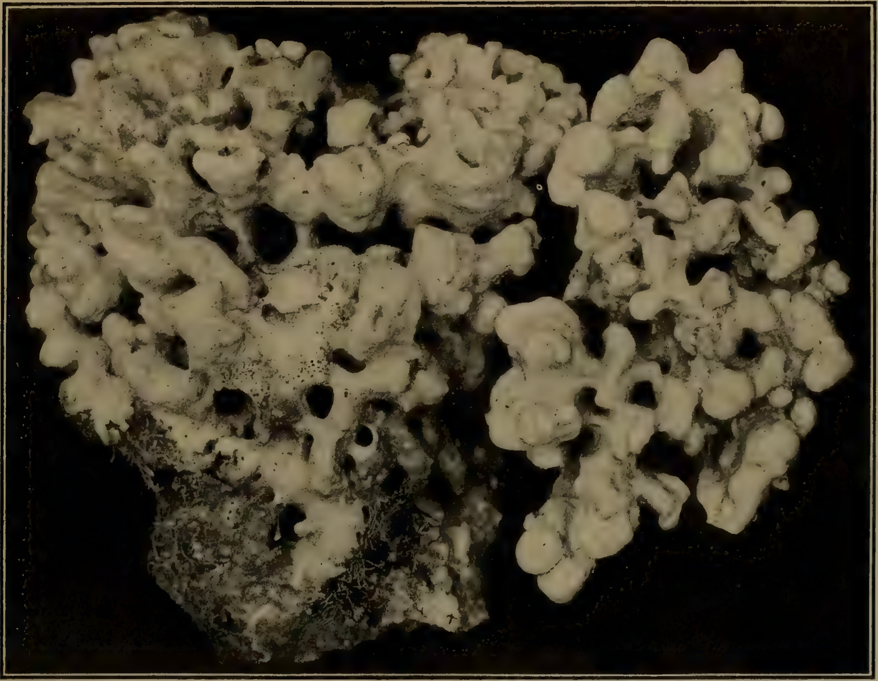

FIGURE 1.—A FRAGMENT OF A MODERN STONY COLONY OF CALCAREOUS ALGÆ (LITHOPHYLLUM ANTILLARUM, FOSLIE AND HOWE)

This specimen from Porto Rico is about 6 inches wide. Reproduced through the courtesy of Dr. Marshall A. Howe, New York Botanical Garden

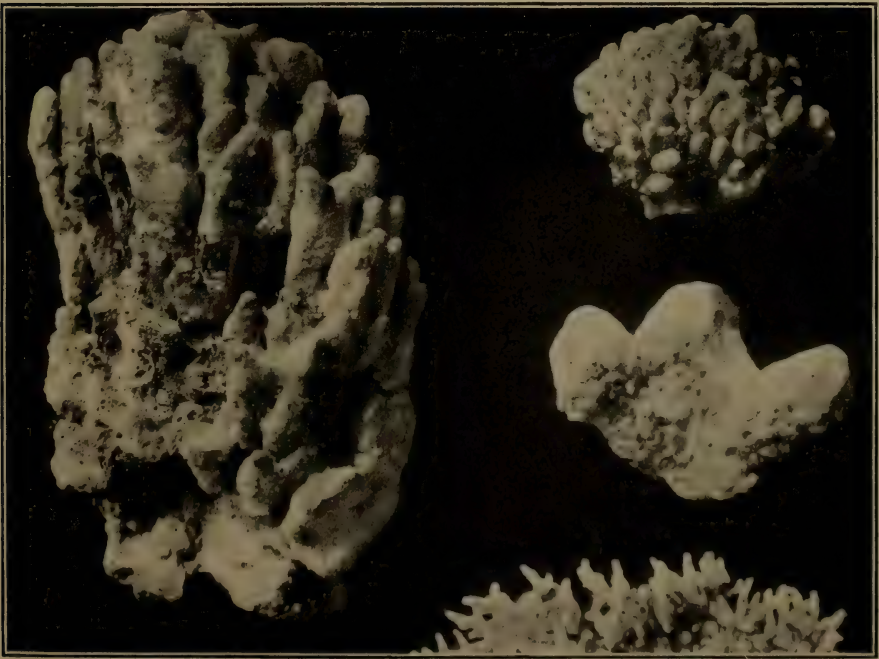

FIGURE 2.—VARIETIES OF STONY CALCAREOUS ALGÆ FROM THE INDIAN OCEAN

Reproduced from the report on "Fauna and Geography of the Maldive and Laccadive Archipelagoes," by Gardner, Foslie, and others

CALCAREOUS ALGÆ

convincing. At least five possible hypotheses may be suggested as worthy of consideration in reference to the Bighorn: (*a*) erosion of preexisting dolomite rock; (*b*) direct chemical precipitation of the mineral dolomite; (*c*) formation directly by organisms secreting dolomitic shells; (*d*) deposition, either organically or chemically, as lime carbonate, but progressively altered to dolomite by magnesian solutions while yet unburied; (*e*) dolomitization of consolidated limestone long after deposition by circulating underground waters. It must also be recognized as a possibility that the true origin of the Bighorn formation involved a more or less complex combination of two or more of these processes.

The first suggestion may be dismissed with scant attention. Although the few layers of calcarenyte are made of fragmental material and show the action of currents, the prevailing beds of the formation do not. Still more convincing is the purity of the dolomite. If of fragmental origin, it would have to be derived from land-masses composed entirely of dolomite; but for so widespread and thick a terrane this seems incredible.

There seems to be but little reason to think that the Bighorn dolomite has been produced by the direct and initial precipitation of the double carbonate through the partial evaporation of sea-water, although some dolomites may have originated in that manner. The whole terrane is evidently marine in origin, and it entirely lacks the characteristics of calcareous deposits produced by the desiccation of inclosed seas. It seems to be true that dolomite has not been found in course of precipitation on any part of the present sea-bottom, nor have chemists thus far devised, so far as I have learned, any laboratory conditions competent to cause the precipitation of dolomite and at the same time likely to be realized on a large scale in oceanic waters. These considerations lead me to seek some other mode of formation as more probable.

Under the third hypothesis it may be supposed that certain early Paleozoic organisms normally constituted their shells of dolomite rather than of lime carbonate, and that the Bighorn rock originally consisted of such remains. Since no organisms are now known to secrete dolomite, this suggestion may appear chimerical to the reader. But it must be admitted that many calcareous creatures of the sea now contain small amounts of magnesium carbonate: corals, 0.1 to 11.0 per cent and coralline algæ, 1.95 to 13.19 per cent.[17] It is conceivable, although perhaps unlikely, that in early geologic periods organisms may have used a much larger proportion of magnesium in their shells. At times of greatly diminished lands, as in the Middle Ordovician, the terrigenous supply of lime salts must have been largely curtailed, and since the ocean even today carries but a small working balance of lime, constantly being drawn on by organisms, it is not entirely improbable that in such expanded epicontinental seas organisms were unable to obtain sufficient lime carbonate for their needs. Daly[18] argues that in the early eras lime must have been practically absent from the sea-water, because of the action of alkali carbonates in removing it from solution; but he concludes that on this account the organisms were unable to provide themselves with calcareous hard parts—on the assumption that they could use no other salt. It is a fact long known to agricultural chemists that most land plants require potassium salts in their metabolism and can not use sodium compounds as substitutes therefor. There is good reason[19] to believe that marine plants, on the contrary, demand sodium. It has been suggested that this fact merely reflects a necessary adaptation to environment, for potassium is the alkali that remains in largest quantity in the soils which accumulate on land, and sodium is by far the most abundant alkali in the sea. Following out this line of thought, it would not seem strange if marine organisms were able to make shift with dolomite as skeletal material when the supply of calcium was inadequate. Nevertheless, the invariable deficiency of magnesia in existing shells leads me to regard this third hypothesis with very little favor.

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[17] F. W. Clarke: Data of Geochemistry. U. S. Geological Survey, Bull. 491, 1911, p. 540.

Reserving the fourth suggestion for more extended examination, we may next consider whether the Bighorn strata were deposited as limestone and afterward converted into dolomite by the action of percolating underground waters, of which the pervasive effects on rocks in general are well understood. There are apparently two methods by which this change could be accomplished: (*a*) by leaching out lime and (*b*) by replacing lime with magnesia.

If this change had been brought about solely by the leaching of lime carbonate from a slightly magnesian limestone, thus increasing the relative proportion of magnesia, we should now find caverns, either empty or refilled, disturbed beds due to slumping, and other evidences of great reduction in volume. All these are absent. If it involved only metasomatism (the substitution of magnesia for lime, ion by ion), the compactness of the rock is explicable, for the dolomitization of calcite in this way should cause a reduction in volume of the mineral grains or, in other words, pore space of only about 4.7 per cent. A careful determination of the porosity of a typical specimen of the Bighorn dolomite has been made for me by Mr. W. J. Mead,[20] and the result arrived at is 1.31 per cent. This shows a porosity about one-fourth as great as the average of five determinations from the Niagara dolomite of Wisconsin,[21] almost the same as that of a typical dense limestone from the Trenton (Platteville) formation of southern Wisconsin, and only about four times as great as the average porosity of such extremely compact rocks as granite, rhyolite, and diabase. This comparison seems to preclude the possibility that the formation has been subject to leaching action on a considerable scale; and although the discrepancy between 1.31 and 4.7 is not great, it affords some ground for suspecting that the dolomite is not a result of the substitution of magnesium for half of the calcium in a normal limestone. I may further point out that the general question of the origin of dolomites by the alteration of limestone has been recently discussed by Steidtmann,[22] with an adverse conclusion. A cogent objection to this hypothesis, pointed out by Steidtmann and others, applies well to the Bighorn and other dolomites of the Paleozoic section in Wyoming; they are underlain by and to some extent even interstratified with beds of pure limestone. The sharp boundaries of these unlike beds of pure limestone ". . . seem to be sufficient proof that the magnesia has not traveled appreciably through the mass of strata since it was originally deposited in the sediments." The same inference is to be made from two thin sections which show parts of corals. In both cases the coral thecæ and septa are wholly dolomitized, but some of the chambers are lined with calcite crystals. These vug fillings are clearly secondary, and the relations indicate that calcite has been deposited from solution while the dolomite remained fixed.

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[18] R. A. Daly: Limeless ocean of pre-Cambrian time. Am. Jour. Sci., 4th ser., vol. 23, 1907, p. 109.

[19] W. J. V. Osterhout: Plants which require sodium. Botanical Gazette, vol. liv, 1912, pp. 532-536.

The remaining (fourth) suggestion to be examined is that the material of the Bighorn dolomite was originally deposited in the form of lime carbonate growths, shells, or ooze, but was progressively altered to dolomite

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[20] The method of determination was as follows: After having been saturated with water by immersion for five days the sample weighed in air 775.2 grams. When weighed in water the result was 500.9 grams. It was then dried for about 24 hours in an oven at a temperature of about 200° centigrade. After this drying its weight was 772 grams. From these data it appears that the sample absorbed 3.2 grams of water. Its porosity was then calculated by the following formula:

$$\frac{\text{Weight dry}}{\text{Weight in water saturated} - \text{Weight in air saturated}} = 3.845.$$

$$\text{Weight in air dry} \times 3.845 = 241 \text{ cc.} = \text{the volume of the rock material.}$$

$$3.2 \text{ grams} = 3.2 \text{ cc. (approx.)} = \text{volume of water absorbed.}$$

$$\text{Porosity} = \frac{3.2}{241 - 3.2} = .0131, \text{ or } 1\ 31/100\text{ths per cent pore space.}$$

[21] Taken from "Building Stones of Wisconsin," by E. R. Buckley. Wisconsin Geological Survey, Bull. IV, 1898.

[22] E. Steidtmann: The evolution of limestone and dolomite. Journal of Geology, vol. xix, 1911, pp. 325-328.

before actual lithification took place, in consequence of chemical reactions in the basal layer of the sea-water in which deposition was proceeding. According to Pfaff,[23] the precipitation of dolomite may be brought about by the presence of either ammonium carbonate, ammonium sulphide, or hydrogen sulphide. These are all common products of the decay of organic matter and are likely to be present in notable quantities in the sediments accumulating on the ocean floor wherever the tissues of marine plants and animals are in process of decay. It appears, however, that in Pfaff's experiments the solutions were considerably concentrated through evaporation. I have found no record of experiments of this kind carried out in such a way as to reproduce closely the conditions on the bottoms of shallow, warm, clear seas.

If it is true that the reactions are chemically feasible in the seas of today or at least were so in the epicontinental seas of Ordovician time, with their somewhat different conditions of temperature, salinity, or biochemical processes, then the hypothesis tends to explain many peculiarities of the Bighorn and similar dolomites. The recrystallization of the mass, which is an essential effect of the postulated process, explains the uniform and moderately coarse-grained texture of these rocks. It likewise accounts for the general lack of caverns, veins, and pores. The hypothesis also affords a ready explanation of the fact that the corals, crinoid stems, and other identifiable animal structures, which originally consisted of either calcite or aragonite, are here fully changed into crystalline dolomite. The vague outlines of the fossil shells and of the problematical algæ may also be accounted for by the process of crystallization, which would give little heed to such boundaries in a chemically homogeneous mass. If, as assumed, this process of converting lime carbonate into dolomite during crystallization took place in the loose sediment lying undisturbed on the ocean floor, there seems to be no reason why it should have affected a layer more than a few inches in depth at any one time. If this view is correct, it helps to explain the altenation of dolomites and limestones in many formations and the fact that the beds underlying the Bighorn formation are pure limestone rather than dolomite.

To this hypothesis of the dolomitizing of lime carbonate deposits in the course of their deposition I find no positive objection, and as it apparently explains most of the observed facts, it seems to me the most promising of the suggestions which have been made. The idea is, of course, not at all new. Daly[24] has recently reached the same conclusion for the dense fine-grained dolomites characteristic of the pre-Cambrian, Cambrian, and Ordovician formations in both eastern and northwestern North America. His comment is that "the evidence shows that the magnesian content of the staple pre-Devonian limestone is original, in the sense that the magnesium carbonate was precipitated from sea-water. In many, if not all, cases the dolomite crystals may have been formed at or near the surface of the ancient calcareous muds by the interaction of the magnesian salts of sea-water with the more easily precipitated calcium carbonate."

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[23] Recorded by F. W. Clarke: Data of Geochemistry. U. S. Geological Survey, Bull. 491, 1911, p. 538.

[24] R. A. Daly: The first calcareeous fossils and the evolution of the limestones. Bull. Geol. Soc. Am., vol. 20, 1909, p. 170.

The subject has also been reviewed by Steidtmann,[25] who concludes that the formation of dolomite in this manner is not only possible, but that an increase in the proportion of magnesium to calcium in the sea-water may be sufficient to bring about dolomitization.

A consideration of the subject up to this point naturally tempts one to go farther and seek a solution for related questions. If the Bighorn dolomite was formed in the way suggested, under what conditions was the change brought about? An answer to this would help us to understand why dolomite was laid down in some parts of what is now the United States at approximately the same time that pure limestone was being deposited in others, and would likewise explain many additional cases, such as the apparent equivalence of the Niagara dolomite of Wisconsin and the Louisville limestone of Kentucky. Experimental work has shown that strong solutions of magnesium salts are deleterious to the growth of animals and plants, but inasmuch as the Bighorn Sea evidently contained abundant living organisms—many of them, like the corals, very delicately adjusted to their environment—it seems unlikely that the magnesium content could have been more than two or three times as great as in the present ocean. Another fact of possible suggestiveness is that the rivers of hot arid regions normally carry a much larger proportion (two to four times as much) of magnesium, as compared with calcium, than do the rivers of cool moist climates. It is also a fact, shown by many laboratory experiments, that the alteration of calcite to dolomite takes place more readily in warm than in cold solutions, and at 100° centigrade the reaction requires hours rather than the centuries which are available for geologic processes. Interesting as these questions are, however, it is not very profitable to discuss them until more is known about the chemical reactions in sea-water of varying temperatures, pressures, salinities, and composition.

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[25] Edward Steidtmann; The evolution of limestone and dolomite. Journal of Geology, vol. 19, 1911, p. 337.

SUMMARY

(1) The Bighorn dolomite is widely distributed in Wyoming, and will probably be found to extend through the northern Rocky Mountains from the Black Hills southwestward to Utah and northwestward to southern Montana; but it is absent in southeastern Wyoming.

(2) It is of Ordovician age and probably includes Silurian also.

(3) Chemically it is a very pure, normal dolomite, almost devoid of terrigenous material.

(4) Fossils are rare and seldom well enough preserved to be identified. The most abundant are corals and crinoid stems.

(5) Its characteristic coarsely pitted and fretted surface is due to the differential weathering, not of siliceous and calcareous matter intermingled, but of compact fine-grained dolomite structures imbedded in a matrix of more coarsely crystalline and more porous dolomite.

(6) The ill-defined branching structures which are directly related to the pattern of the weathered surface are probably of organic origin. It seems more likely that they represent banks of calcareous algæ than any of the plant-like animals.

(7) The obliteration of the original organic structures is assigned to the process of crystallization of the dolomite.

(8) In origin the mass of the rock is not in large measure fragmental, was probably not directly precipitated as dolomite or as dolomitic shells, and probably has not been produced by the substitution of magnesium for calcium in a solid limestone. It is suggested as most probable that it has been produced by the almost simultaneous interaction of the bottom layer of sea-water, charged with magnesium salts, on shells, skeletons, and other particles of calcite and aragonite accumulating as loose sediments on the sea-floor.

(9) The deposits were probably made in an epicontinental sea less than 100 to 200 meters in depth; and there are considerations which suggest that the water was warm, somewhat (but not much) above the average in salinity, and contained more than the usual amount of magnesium salts.

In conclusion, it gives me pleasure to acknowledge valuable suggestions on the reef-making coralline algæ of modern seas from Dr. Marshall A. Howe, of the New York Botanical Garden, and from Dr. C. I. Lewis, of the University of Wisconsin, on various botanical questions concerning the algæ. Doctor Howe also kindly loaned the photographs of *Lithophyllum antillarum* which are used here as illustrations.

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INDEX TO "REVISION OF THE PALEOZOIC SYSTEMS" *

BY E. O. ULRICH

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* Prepared for the the author by Mr. John M. Nickles, of the U. S. Geological Survey.

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E. O. HOVEY, *Secretary*

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EXPERIMENTAL GEOLOGY, ONE OF THE LARGE SUBDIVISIONS OF GEOLOGY

BY FRED E. WRIGHT

(Abstract)

Experimentation has long been employed in geology as an indirect means of approaching the solution of certain problems by a process of analogy; such initiative experiments have met, however, with only a moderate degree of success, and in recent years have been largely replaced by direct measurements on reproducible systems of definite composition subjected to known conditions of temperature and pressure. This change in mode of attack has been made possible by the rapid development, during the past three or four decades, of physics and chemistry; this in turn has led to a better appreciation of the fundamental principles involved in many geological problems and has placed at the disposal of the geologist methods of attack which enable him to solve problems hitherto deemed beyond the range of experiment. This part of geology is not usually presented in the text-books, but its importance is so great that it merits detailed treatment and may properly be considered a dis-

tinct subdivision of geology of equal rank with petrology, stratigraphy, economic geology, etcetera.

Discussion

Dr. A. W. **Grabau**: I would suggest that the workers in experimental geology get out a syllabus or small text-book setting forth the present status of the subject and giving methods of procedure to carry on simple experiments such as require only simple apparatus; also to suggest lines along which investigations can be carried on. The mass of detail accumulated ought to be digested and summarized, so that the busy geologist can master it without too much expenditure of time and energy.

STRUCTURAL GEOLOGY OF THE HANOVER DISTRICT, NEW HAMPSHIRE

BY JOHN WESLEY MERRITT[1]

(*Abstract*)

The circular map (figure 1) shows belts of highly metamorphosed sediments wrapping around an elliptical area of granite.

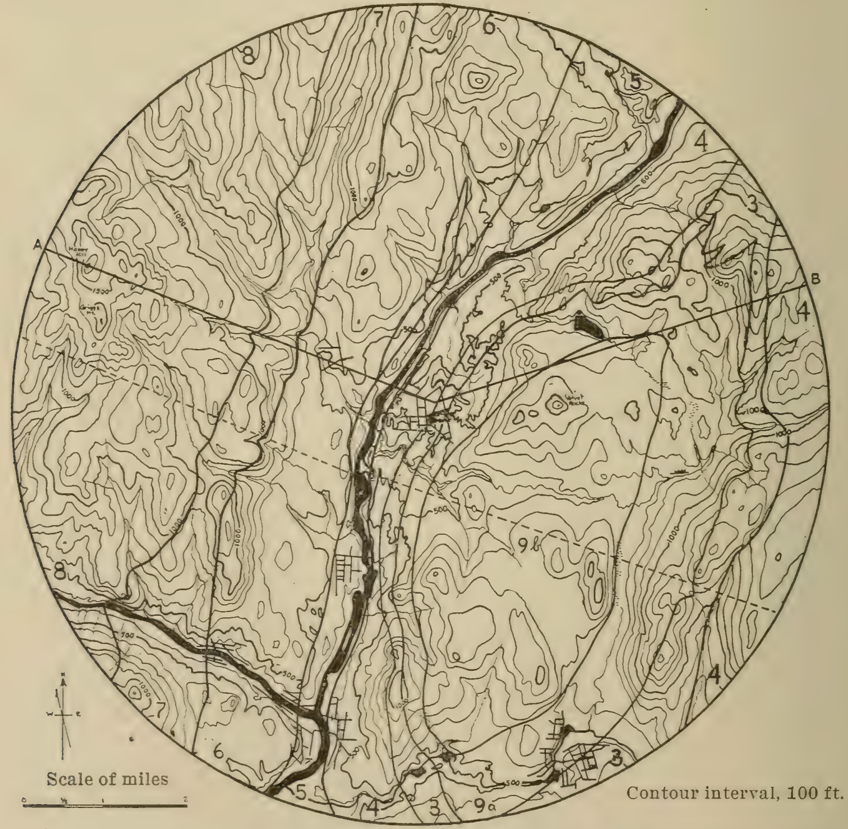

Figure 1.—*Topographic and geologic Map of the Region within 5 Miles of Hanover, New Hampshire*

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[1] Introduced by James Walter Goldthwait.

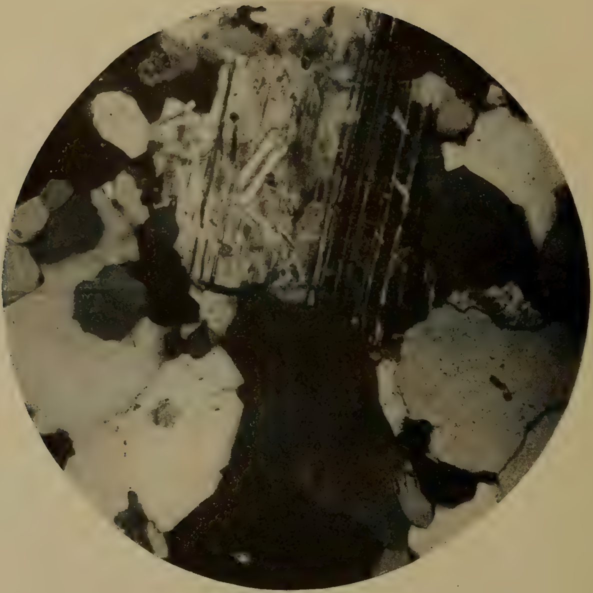

Figure 1.—Lebanon Granite (9*b* on Figures 1 and 2)

Crossed nicols × 87

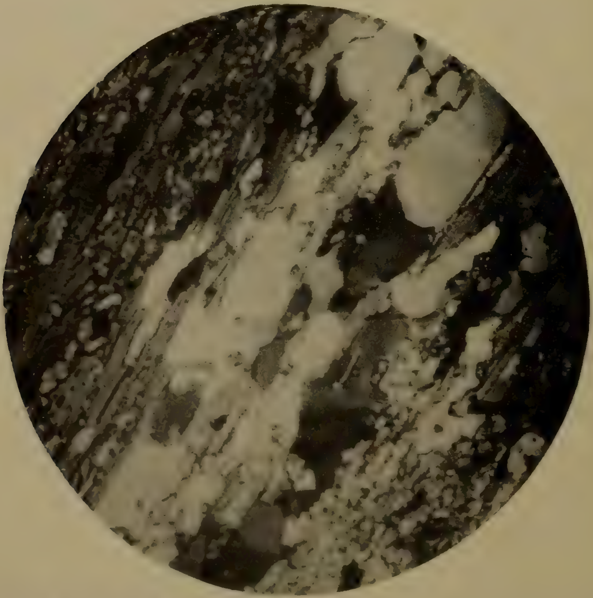

Figure 2.—Border Zone Granite Gneiss (9*a* on Figures 1 and 2)

Crossed nicols × 87

LEBANON GRANITE AND BORDER ZONE OF GRANITE GNEISS

While previous work[2] on this district showed that this igneous rock was younger than the overlying sediments, it did not show its relation to the metamorphism of those sediments, the structure, or the interrelation of the central core of granite to the border-zone phase.

The structure (figure 2) is that of an eroded dome, with granite at the center. There are two phases of this granite: (1) a central mass, 9*b*, which is pink or very light gray, not deeply weathered, and shows practically no foliation; and (2) surrounding this, a border zone of granite gneiss, 9*a*, showing considerable foliation in places, and differing in composition in the absence of muscovite and the presence of a much larger content of basic mineral. This is cut in places by dikes of the younger granite and was rendered schistose either before or during this intrusion. Overlying the granite-gneiss border zone are the following, in ascending order: sandy schist with squeezed quartzite pebbles, 3; slate and mica schist, 4, and quartzite conglomerate, 5. All of these have been intensely foliated and variously affected by contact metamorphism. The argillaceous rocks are altered most. The alteration is so great in places that the metamorphic rocks are distinguished from igneous rocks with difficulty. The new minerals formed are hornblende, garnet, and chloritoid, the hornblende in places composing more than half of the rock. Often the quartzite is rendered micaceous, a white quartzite becoming speckled and resembling light gray granite. Sometimes the quartzite conglomerate, especially where some argillaceous material occurs within it, is highly altered and difficult to recognize. In all cases, however, the original sedimentary character of these rocks may be recognized in thin sections, and in most cases in the hand specimen when closely studied. Occasional trap dikes cut the granite and the sediments near their contact with the granite.

On either side of this dome is a synclinal fold, the one on the west, however, showing younger sediments, which have been removed from the syncline to the east (figures 1 and 2).

Professor Hitchcock[3] describes certain "inclusions" as "fragments of the adjacent mica schist." It is to be noted, however, that these "inclusions" are found all the way from the outside edge of the border zone to the center of the Lebanon granite, a distance of no less than a mile from the border. It is difficult to conceive how fragments, most of them less than two inches in diameter, could be carried to that distance from the contact and

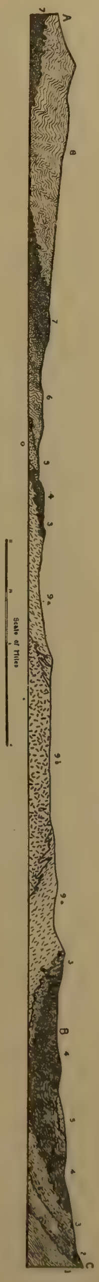

FIGURE 2.—*Geologic Section along the Line AB on Figure 1*

BC lies without the area shown in Figure 1. 1 = non-calciferous chlorite schist; 2 = quartzite; 3 = sandy mica schist; 4 = slate; 5 = quartzite conglomerate; 6 = calciferous chlorite schist; 7 = slate and phyllite; 8 = sandy schist; 9*a* = border zone rock; 9*b* = Lebanon granite.

Relation of vertical scale to horizontal = 160 : 211.

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[2] C. H. Hitchcock: Geology of the Hanover, New Hampshire, quadrangle. Sixth Report of the State Geologist of Vermont, 1908, pp. 139-186.

[3] Op. cit., p. 165.

not be dissolved. They contain the same minerals as the rest of the granite, but with a larger amount of ferromagnesian minerals, and have a granitoid structure. They might better be regarded, therefore, as basic segregations which took place within the magma during its crystallization.

EFFECT OF HIGH PRESSURES ON THE PHYSICAL AND CHEMICAL BEHAVIOR OF SOLID SUBSTANCES

BY JOHN JOHNSTON AND L. H. ADAMS[1]

(*Abstract*)

This paper is an endeavor to review and define the present status of our knowledge of the effect of high pressures on the behavior of solids, to reconcile some of the conflicting statements to be found in the literature pertaining to the subject, and to indicate the conclusions which may justifiably be drawn from the available evidence, especially with regard to their application to the discussion of geological phenomena. Some of this confusion results from the employment of indefensible criteria in ascertaining the character and magnitude of the change produced by pressure, as, for example, in determining the effect of pressure in promoting chemical reaction between solids; but in the main it is due to failure to take into account the fact that the effects produced depend on the character, or mode of action, of the compression. The effects are different, namely, according as we are dealing with pressure uniform in all directions (true hydrostatic pressure) or with a mode of compression which does not satisfy this condition; in other words, the effects vary—as, indeed, is almost obvious—according as the solid retains its original form or undergoes deformation.

Uniform pressure has a comparatively slight effect on the melting point: it usually raises it, and by an amount, which in the systems hitherto investigated, is seldom greater than 10°, and never greater than 30° per 1,000 atmospheres. Its effect on solubility is slight, and for practical purposes negligible as compared with the influence of temperature upon solubility. Uniform pressure tends to further those reactions which are accompanied by a decrease of volume; but it by no means follows that it will cause these (or other) reactions to occur; for whether a reaction takes place or not is determined by its velocity under the particular conditions, and such evidence as there is tends to show that reaction velocity is not much affected by uniform pressure.

The effects of non-uniform pressure greatly outweigh those of uniform pressure. It *always* lowers the melting-point and raises the solubility, and by amounts which are many times greater than the corresponding changes with uniform pressure. Indeed, if we make the plausible assumption that permanent deformation of a crystalline aggregate is conditioned by a real local melting (of those parts which at any moment bear the brunt of the load), we find the amount of pressure required to cause melting at ordinary temperature to be well within the bounds of probability. Such we believe to be the efficient cause in producing most of the phenomena recorded as occurring when solid systems were submitted to compression. This view, while it coordinates satisfactorily the whole of the experimental work hitherto done, conflicts with none of the available direct evidence.

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[1] Introduced by A. L. Day.

It follows, therefore, that we can determine the effect of pressure on a solid system only if we can define the character of the compression (with reference to its approach to uniformity or otherwise) as well as its magnitude, and even then only when the requisite thermal and other data characteristic of the system are available.

Discussion

Prof. H. F. **Reid**: Prof. James Thomson explained the flow of glacier ice as the result of melting and regelation. This theory was accepted for a time, but latterly glacialists have inclined toward the idea of ordinary plastic flow of glacier ice. Must we now go back to Thomson's theory as the explanation of plastic flow? When a copper wire is bent do we have melting of the particles of the wire? This is a new conception of plasticity.

Dr. A. L. **Day**: The theory is not entirely new, but this is, so far as I know, the first attempt to extend it to cover such a wide range of phenomena and to differentiate definitely between the effects of uniform (hydrostatic) and non-uniform compression.

STRUCTURAL FEATURES OF A PORTION OF SOUTHEAST IDAHO

BY R. W. RICHARDS AND G. R. MANSFIELD

(Abstract)

For the past four years the United States Geological Survey has carried on detailed geologic work in southeast Idaho for the purpose of securing data for classifying public lands supposed to contain deposits of phosphate. The phosphate occurs in rocks assigned to the Permian, and is accompanied by a rather full series of Paleozoic and Mesozoic rocks. The whole sedimentary series is thrown into pitching folds, with trend curving from nearly north-south to northwest. The larger folds are relatively simple, but about their margins there are frequently faults and subordinate folds that make the structure complex. The folded region is traversed by a great thrust fault, the Bannock thrust, with warped plane and irregular trace.

BANNOCK THRUST—A MAJOR FAULT IN SOUTHEAST IDAHO

BY R. W. RICHARDS AND G. R. MANSFIELD

(Abstract)

The work of members of the United States Geological Survey in the phosphate reserve of southeast Idaho during the years 1909-1911 has led to the recognition of an overthrust fault that appears to have unusual extent and magnitude.

Several faults at first supposed to be independent are now interpreted as parts of a single great thrust, the plane of which has been warped and partly unroofed by erosion. This great fault has been called the Bannock thrust from Bannock County, Idaho, where it is well displayed.

Rocks of Cambrian to Mississippian age have been thrust on Triassic to

Cretaceous formations, involving vertical displacements of 8,000 to 12,000 or more feet. The horizontal displacement is estimated at not less than 12 miles, while the zone of movement was probably as much as 35 miles wide. The fault with its irregular trace extends at least 270 miles.

DISCUSSION

Dr. **ELIOT BLACKWELDER**: The Willard thrust in the Wasatch Mountains, referred to by Mr. Mansfield as possibly part of the Bannock thrust, seems to indicate movement of the overriding block from east to west. This is inferred from the drag-folds underlying the thrust block.

The announcement was made that in the Snake River Range Carboniferous beds have been found in contact with the Cretaceous, suggesting a northward continuation of the Absaroka fault; and also that there are overthrusts along the southwest side of the Wind River Mountains, which were first noted by C. L. Baker in 1909. On the Wind River thrusts the Archean overrides from the northeast the Carboniferous and even Cretaceous.

Mr. Mansfield was asked whether the warping of the Bannock thrust was contemporaneous or subsequent. The reply was that the facts were not suggestive on that point.

ANGULAR UNCONFORMITY AT CATSKILL

BY GEORGE H. CHADWICK

(*Abstract*)

Recent changes in the water level of Catskill Creek, New York, have brought to light new and striking evidences of the unconformity between Lower and Upper Silurian (Champlainic-Ontaric) rocks.

DISPLACEMENTS OF TRIANGULATION STATIONS IN SUMATRA DUE TO AN EARTHQUAKE IN 1892

BY HARRY FIELDING REID

(*Abstract*)

An earthquake occurred in Sumatra in 1892 when the secondary triangulation of the island was in course of execution. A number of survey stations were displaced by the disturbance. All the displacements, both in amount and direction, can be accounted for by assuming a horizontal slip on a fault similar to that which occurred at the time of the California earthquake of 1906.

SOME STRUCTURAL FEATURES IN THE NORTHERN ANTHRACITE COAL FIELD

BY N. H. DARTON

(*Abstract*)

In collecting data for constructing a contour map of the structure of the northern anthracite coal basin many interesting details of structure revealed by mining have been obtained. Some sections show marked irregularity in

form in different parts of the same flexure and illustrate the difficulty in interpreting underground structure from surface observations. Rock texture is an important factor in influencing the minor crenulations. In this connection some account was given of the construction of the structure map, especially in areas where the coal has not yet been mined.

GEOTHERMAL DATA OF THE UNITED STATES

BY N. H. DARTON

(*Abstract*)

This contribution consists of all available records of underground temperatures in the United States. Some of the data are compiled, but there are also presented results of observations by the author and his associates with a special type of thermometer in deep borings and mines. Temperatures of many artesian flows are included in the list. Some of the geologic relations of the thermal gradients in certain districts are described and their probable cause considered.

MAGNITUDE OF CONTINENTAL DEPOSITS[1]

BY CHARLES R. KEYES

(*Abstract*)

With the constantly and rapidly growing appreciation of the importance of those sediments now widely known as continental deposits, the establishment of critical criteria for their discrimination has not kept pace. Certain of these criteria need especial emphasis. In the genetic determination of some of the more recently formed terranes, such as are found on the American continent west of the Mississippi River, physiographic criteria are most useful.

Of continental deposits those strictly fluviatile in origin are probably of far less importance than has been supposed. Those of eolic nature appear to be much more widely distributed and greater in extent than usually ascribed. Wind-blown materials which come finally to rest in the ocean seem to constitute a very considerable proportion of the sediments of all geologic ages that are now commonly regarded as essentially marine beds. Some Paleozoic formations lately considered as eolic in character are believed not to be such.

When carefully evaluated, it may prove that fully one-half of all known geologic formations belong to the continental mass of deposits.

GLACIAL CIRQUES NEAR MOUNT WASHINGTON

BY JAMES WALTER GOLDTHWAIT

(*Abstract*)

Several of the "ravines," "gulfs," or "basins" on the flanks of Mount Washington and neighboring summits of the White Mountains have distinct cirque form. They lie on all sides of the range, and can not be explained as products of glaciation by the ice-sheet which covered the summits. They seem surely to have been carved out by local glaciers of the Alpine type.

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[1] Read by title December 28, 1912.

That this vigorous local glaciation occurred before and not after the regional glaciation of the range is indicated by (1) the absence of valley moraines at the cirque mouths and (2) the extension of the regional ground moraine far up their floors. Rock falls and avalanches have given a pseudo-morainic effect to the upper portions only of the cirque floors.

Agassiz's theory of a former existence of local glaciers in the White Mountains is thus supported by new facts; but these glaciers seem to have been very much shorter than hitherto supposed, and instead of having existed in a closing stage of the last glacial epoch they seem to have operated in an early stage or quite probably in an earlier epoch.

Discussion

Mr. **Frank Leverett** inquired whether Doctor Goldthwait had found a suitable explanation for the growth of local glaciers in the Mount Washington region in advance of the invasion of that region by the continental ice-sheet. He also asked whether Doctor Goldthwait had found evidence that the wind-deepened valleys that had held the local glaciers were free from ice when the continental ice-sheet moved across them.

Prof. **H. F. Reid**: Professor Goldthwait's paper supplies me with some information regarding the position of the snow-line during the retreat of the great ice-sheet which I have long wanted to have. When Mount Washington was uncovered by the retreat of the ice, glaciers would have been formed on its flanks if the snow-line were somewhat lower than the summit, and the fact that no such glaciers were formed shows that the snow-line must have been at an altitude of 6,000 feet or more when Mount Washington was uncovered. On account of the sloping surface of the ice the snow-line must have been some distance farther to the north.

Prof. **J. B. Woodworth**: On the Island of Marthas Vineyard there is evidence of a long interglacial epoch of erosion between the Wisconsin and the next preceding epoch of glaciation. If these cirques on Mount Washington were produced by local glaciers prior to this interglacial epoch, their walls seemingly should have been notched by gullies and corries, which may still persist in part as evidence of non-glacial action prior to the advent of the Wisconsin ice. The absence of these non-glacial erosion features would be presumed to mean that the local glaciers preceded the Wisconsin immediately or by a time so short that weathering and rain action produced no such effect in any recognizable degree.

GEOLOGICAL SECTION ALONG THE YUKON-ALASKA BOUNDARY BETWEEN YUKON AND PORCUPINE RIVERS

BY D. D. CAIRNES

(Abstract)

The geological investigations conducted during the past two summers along the Yukon-Alaska International Boundary (the 141st meridian), between Yukon and Porcupine rivers, have shown that the rocks there are dominantly of sedimentary origin, and include Mesozoic, Paleozoic, and probably Archean members, the entire Paleozoic section being apparently represented.

Graptolites, which are believed to have been found in only three other localities in Alaska, Yukon, and the Northwest territories, were obtained at one point. Cambrian fossils were also found at several points, which extends considerably our knowledge concerning the Cambrian, as fossil remains of this period have not previously been discovered in Yukon Territory, and in Alaska have been found at but one other locality, over 700 miles to the west.

Members of the older schistose formations which have heretofore been considered as pre-Devonian, pre-Silurian, or pre-Ordovician were found stratigraphically lower than certain limestone beds in which Middle Cambrian fossils occur, and are thus of Lower Cambrian or pre-Cambrian age. These schistose rocks are of considerable importance, since they have been shown to be the source of the gold of all the known Yukon placer deposits, as well as a large portion of those of Alaska.

RED BEDS BETWEEN WICHITA FALLS, TEXAS, AND LAS VEGAS, NEW MEXICO, IN RELATION TO THEIR VERTEBRATE FAUNA

BY E. C. CASE

(*Abstract*)

This paper described a trip from Wichita Falls, Texas, across the Permian and Triassic Red Beds of western Texas and eastern New Mexico. A study of the beds was made from where they appear on the east, in close relation with the Pennsylvanian limestone, to where they turn on the flanks of the Rocky Mountains at Las Vegas Hot Springs, in New Mexico. Especial attention was paid to the character of the beds in an attempt to determine the nature of the deposition and the climatic and other changes recorded. The ultimate aim of the study was to determine, so far as possible, the conditions of life and distribution of the vertebrate fauna of the so-called Permian Red Beds of north central Texas and adjacent parts of Oklahoma.

SHINARUMP CONGLOMERATE

BY HERBERT E. GREGORY

(*Abstract*)

The Shinarump conglomerate probably constitutes the base of the Triassic in the Colorado Plateau Province, and is separated from the underlying Permian by a widespread erosional unconformity. The Shinarump of Powell and Dutton is to be correlated with part of the Lithododendron of Ward, but not with the Dolores conglomerate exposed in southwestern Colorado.

DISCUSSION

Dr. A. W. GRABAU asked how the Shinarump conglomerate and the limestone conglomerate of the Dolores were formed.

Professor GREGORY replied that there was as yet no satisfactory explanation.

Mr. N. H. DARTON: Regarding the unconformity at the base of the Shinarump, there was no conclusive evidence one way or the other in exposures near the line of the Santa Fe Railroad. There is an abrupt change in character of sediments and more or less channeling of the surface of the underlying shale.

but a relation of this sort is usual in conformable sequences where a coarse sediment has been deposited on fine-grained material. Now that Doctor Gregory has established the presence of an unconformity by finding overlaps in the region to the north, it appears that this must be the relation also in the area near the railroad.

It appears to me that the coarse deposits of the Shinarump are in broad, irregular zones which represent the channels of streams that flowed in various directions over the surface, probably mainly during times of freshets.

FURTHER DISCOVERIES IN THE TACONIC MOUNTAINS

BY ARTHUR KEITH

(*Abstract*)

A paper presented by the author to the Society at its last meeting described the various limestones which sweep around the slate mass forming the north end of the Taconic Mountains in Vermont. During this fall further work by the author on the slates of the mountains supports the conclusion stated last year, that the contact of the limestone and slate is a fault contact, with the limestones (Stockbridge) lying under the slates.

By detailed work the slates have been mapped and subdivided into seven formations, five of which are at some point in contact with the limestone. These formations are in brief: (1) at the top green, greenish gray and whitish gray slate; (2) massive, vitreous white quartzite; (3) greenish gray slate, with thin seams and beds of green quartzite and cherty quartzite; (4) black slate; (5) calcareous, ferruginous quartzite; (6) blue slate, with blue limestone lentils; (7) gray slate, with thin gray or whitish quartzite seams and layers. At the west side of the Taconic Mountains the argillaceous beds are slates, but become phyllites or fine schists at the east by increase of metamorphism. This is most seen in the top and bottom formations and least in the black slate, ferruginous quartzite, and limestone. Lower Cambrian fossils are found in the limestone lentils of the blue slate, while the ferruginous quartzite has always been recognized as characteristic of the Cambrian. All these formations, including the known and characteristic Cambrian horizons, pass through dozens of pitching folds, entirely across the north end of the Taconic Mountains from west to east.

Inasmuch as the divisions of the Ordovician Stockbridge limestone in this area dip under the slates known to be Cambrian and these in turn dip and pitch away from the limestones, and inasmuch as the limestones and slates are all unconformable with the general contact, an overthrust of the slates seems the only competent explanation of their relations.

PRELIMINARY GEOLOGICAL MAP OF THE NAVAJO-MOKI RESERVATION

BY HERBERT E. GREGORY

(*Abstract*)

Reconnaissance in northeast Arizona and southeast Utah shows a widespread distribution of the Permian, Triassic, Jurassic, Cretaceous, and Tertiary strata, previously known to occur in southwestern Colorado. Volcanic necks, dikes, and remnants of lava flows are distributed throughout the area.

VARIOUS FORMS OF SILICA AND THEIR MUTUAL RELATIONS

BY CLARENCE N. FENNER

(*Abstract*)

The results of laboratory investigation on the conditions of formation of the SiO_2 minerals, quartz, tridymite, and cristobalite are given, and the bearing which this has on their occurrence in nature is discussed. The inversion point of quartz into tridymite has been determined as 870° + 10° and that of tridymite into cristobalite as 1,470° + 10°. These points define the ranges of stability of these minerals, and under proper conditions the appropriate form will always appear, but under certain circumstances tridymite and cristobalite may be formed outside of their range of stability and will persist indefinitely. This has an important bearing on their occurrence in nature. Quartz, on the other hand, does not appear to be formed above 870°, except that great pressure will raise the inversion point to some degree. The thermometric point thus established places a probable upper limit to the crystallization of quartz from magmas.

INDEX-ELLIPSOID IN PETROGRAPHIC-MICROSCOPIC WORK

BY FRED E. WRIGHT

(*Abstract*)

In this paper the importance of presenting the subject of microscopical petrography consistently from the viewpoint of the index-ellipsoid as applied to the wave front normals (without reference to the rays) is emphasized. The various optical properties employed—practical petrographic microscope work—can be best described and explained systematically by means of the index-ellipsoid. The use of the so-called "axes of elasticity," or $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$, or X, Y, Z in this connection is confusing, and only adds to the difficulties encountered by the observer in mastering the subject. They should accordingly be abandoned, and the French usage of naming the principal axes of the index-ellipsoid α, β, δ (or n_p, m_m, n_g) adopted. To employ "axes of elasticity" ($\mathfrak{a}'$, $\mathfrak{c}'$ or X', Z') in the expression for extinction angles is not only needless, but less direct, as it introduces entirely new conceptions which experience has shown only tend to bewilder the student. Clear, concise modes of expression and simple methods of attack are as essential in petrology as in other sciences whose development is often directly dependent on the care and attention given by its workers to these factors.

DISCUSSION

Dr. E. B. MATHEWS: Estimating Doctor Wright's suggestions from my own experience as a worker and teacher, I can concur with his judgment that it is helpful to use the indicatrix and the ellipses desired by the intersection of its surface by the plane of the microscopic section. This is particularly true for the more mature workers. Although in my teaching during the last decade I have used the indicative with varying emphasis and found the practice satisfactory, I have found certain phases of the subject of petrographical or optical mineralogy which appear to be taught more easily by one of the other geometrical conceptions enumerated by Doctor Wright. For example, the average student appears to grasp the reasons for the white light phenomena in a section perpendicular to an optic eye more readily by a consideration of the ray paths or the wave-surface normals. Again, the teacher's task involves the development of the use of the literature by students. The student is offered the dilemma of using the English texts with 𝔞, 𝔟, 𝔠 (or *X*, *Y*, and *Z*) or the French texts with an indicatrix oriented in terms of the unfamiliar crystallographic notation of the French. For this reason it seems more advisable to retain several of the geometrical conceptions in teaching in spite of a possible initial confusion on the part of the student.

IGNEOUS COMPLEX OF HIGH TITANIUM-PHOSPHORUS-BEARING ROCKS OF AMHERST-NELSON COUNTIES, VIRGINIA

BY THOMAS L. WATSON AND STEPHEN TABER

(*Abstract*)

The area described is located along the western edge of the Piedmont Plateau and near the southeastern slope of the main Blue Ridge, within the foothills, about half way between Charlottesville and Lynchburg, Virginia. The rocks of the area are igneous in origin, are intensely metamorphosed, and are divisible into a number of types which show marked kinship chiefly in a combination of particular mineralogical and chemical characters. The principal rock types include (1) quartz-monozite gneiss, (2) syenite, (3) gabbro, (4) nelsonite, and (5) diabase. In general the rocks are characterized by the prominence of apatite and the titanium minerals—rutile, ilmenite, and in places titaniferous magnetite; by a peculiar blue opalescent quartz, and by pyroxene (chiefly hypersthene) or secondary hornblende derived from pyroxene as the dominant femic silicate mineral.

The paper describes the general geology and petrology of the area in considerable detail, and the relationships of the rock types are discussed on the basis of microscopic study of thin sections and complete chemical analyses. The norms of the rocks are computed and their positions in the quantitative system of classification shown. Several new rock types are described and magmatic names suggested for them.

PETROLOGY OF A SERIES OF NEPHELINE SYENITE, CAMPTONITE, MONCHIQUITE, AND DIABASE DIKES IN MIDDLE SHENANDOAH VALLEY, VIRGINIA

BY THOMAS L. WATSON AND JUSTUS H. CLINE

(*Abstract*)

This paper embodies a petrologic study of a series of igneous dikes occurring in Augusta, Rockbridge, and Rockingham counties, Virginia, which form a part of the middle Shenandoah Valley. The rock types represented are diabase, including both normal and olivinic forms, nepheline syenite, camptonite, and monchiquite. Occurrences of diabase have previously been noted and described in middle western Virginia by the Campbells, Fontaine, Darton, and Watson, but recent investigations by the present writers have revealed numerous other dikes of diabase in various parts of the three counties mentioned above.

In addition to diabase, a series of complementary dikes of nepheline syenite, camptonite, and monchiquite, intimately and interestingly associated with each other, occur in the northern part of Augusta County, cutting the Shenandoah group of limestones and the Mississippian rocks in Little North Mountain. The dikes closely parallel each other and can be traced for long distances across the valley limestone and related formations and the later rocks of the Allegheny ridges to the west, but in no case have they been traced farther east than the foothills of the Blue Ridge. Kinship of the three rock types is established by particular characters in mineralogical and chemical composition. Hydrochloric acid solution of each rock yields copious gelatinous silica on evaporation.

The rocks are of especial interest, since they mark the first occurrence yet noted in the southeast Atlantic States. The geographic distribution and geologic occurrence and relations of the dikes are described; microscopical petrography based on study of many thin sections, and chemical composition based on complete analysis of the different rock types are discussed, and from their calculated norms the position of the rocks in the quantitative system of classification is determined.

NORTHUMBERLAND VOLCANIC PLUG

BY H. P. CUSHING

Published as pages 335-350 of this volume.

DISCUSSION

Dr. L. V. **Pirsson** called attention to the fact that Dr. John S. Flett at the meeting of the British Association for the Advancement of Science, at Dundee, in the summer of 1912, read a paper on the petrology of Scotland, in which the view was expressed that the pillow lavas represent a series of effusive rocks of peculiar nature poured out under conditions of great stability and geologic quiet and associated with sediments undisturbed at the time. If this view be correct, it would indicate that the hypothesis of the lava having arrived at its present place by thrusting may be correct.

Prof. J. **Volney Lewis**: In some half a dozen localities in the Watchung Mountains of New Jersey a pillow structure very similar to that described by Professor Cushing occurs in the upper parts of the Newark basalt flows. The spheroidal masses are covered with an inch or two of glass, are imbedded in glass, and are characterized by abundant radial cracking. These basalt flows are associated with sediments in which no evidence of marine sedimentation has yet been found and which are apparently of continental origin. It seems impossible, therefore, to attribute the pillow structure to submarine flow.

Dr. I. C. **White**: The failure to note the occurrence of this outcrop of igneous rock in New York by the older geologists and former State surveys has a parallel in my own State of West Virginia. A narrow dike of peridotite occurs in Pendleton County which remained unnoticed by William B. Rogers and his assistants of the Virginia Survey until it was finally discovered by one of the geologists of the United States Geological Survey half a century later.

Another and more conspicuous occurrence of a peridotite dike cutting through the great Pittsburgh coal bed and extending nearly to the top of the hills in

Fayette and Greene counties, Pennsylvania, was also overlooked by the geologists of the first Geological Survey of Pennsylvania, as well as by those of the Second Survey of that State, and finally by those of the United States Geological Survey, who, under Mr. M. R. Campbell's supervision, covered the area described in the Uniontown-Masontown Folio with much more detailed studies than either of the former surveys. It remained for the entry of a coal company to run up against this almost impenetrable wall of igneous rock, nearly 20 feet thick, before the geologists learned of the presence of this dike, which Mr. Hice states can now be traced westward across the Monongahela River into Greene County from the locality of its first discovery in the Masontown coal field of Fayette County.

LAVAS OF HAWAII AND THEIR RELATIONS

BY WHITMAN CROSS

(*Abstract*)

The Hawaiian Islands, using the term in its comprehensive sense, form a particularly well defined petrographic province. Their lavas are clearly comagmatic. A review of the known varieties of these lavas brings out several points of interest in current petrological discussion.

While basalt of a common type is the predominant rock of the islands there is a much greater variety than is commonly supposed. The range of known rocks is reviewed. Chemical characters are discussed on the basis of thirty-nine existing analyses, showing many of the rocks to be of so-called alkaline types.

The relations of the magmas as differentiation products are compared with those of other island groups of the Pacific Ocean, and the distribution of the Hawaiian types in other parts of the world is considered.

It is shown that the distinction between the "Atlantic and Pacific branches" of igneous rocks is highly fallacious as regards both geographic distribution and genetic relations.

PRODUCTION OF APPARENT DIORITE BY METAMORPHISM

BY ARTHUR KEITH

(*Abstract*)

In the southern Appalachians there is a group of rocks with the composition of diorite and the holocrystalline texture of a plutonic rock. These have been described by various authors as "quartz diorite" and an igneous origin has been attributed to them. Objections to such an assignment have been known from the first discovery of the rock, prime among them being its habit of grading into the inclosing sedimentary rocks. Observations accumulated by the author during the last twenty years on occurrences of this diorite scattered over many thousand square miles now seem to justify attributing the formation of this rock to metamorphism.

The rock occurs in bodies of various shapes, in which an ellipsoidal element is usually seen. In places it forms sheets with rounded or lenticular edges and rarely has the aspect of a lenticular dike. The most prominent relations

to other rocks are: (1) its grading or merging into the inclosing rocks; (2) its occurrence only in graywacke, feldspathic gneiss, highly altered feldspathic sandstone, or metamorphic rocks of that general composition; (3) its small dimensions, its thickness rarely as great as 3 feet; (4) the absence of any related or similar igneous rock in the regions marked by the occurrence of the "diorite" bodies; (5) its presence in rocks of this composition at many Cambrian and pre-Cambrian horizons; (6) its occurrence in these small bodies over many thousands of square miles.

Mineralogically the "diorite" consists of quartz, hornblende or biotite, garnet, albite and oligoclase, zoisite, titanite, and sulphides, generally in this order of abundance. These are arranged so that the new minerals replace the structures and minerals of the inclosing rocks, and usually have a random arrangement of their prisms in strong contrast with the schistosity of the older rocks. This is quite marked where the minerals of the "diorite" merge into the graywacke or are formed, as often happens, in patches or single crystals outside of the main part of the "diorite." The most striking form of "diorite" is a spheroidal or ellipsoidal ball from a few inches to a foot or so in diameter, replacing graywacke. These forms consist of a series of shells of different mineral composition, some balls having six or seven shells plainly shown.

The conclusion is reached that the "diorite" results from static metamorphism of the graywacke or similar rock under intense pressure, but with scarcely any differential motion. For lack of a suitable term, pseudo-diorite is the best for present use. These occurrences raise anew the question of the formation of igneous rocks from sediments by fusion, for these pseudo-diorites have the characters of igneous rocks and are plainly derived from sediments. It appears in them, however, that it is not mass fusion which is responsible for their production, but mineral recrystallization by solutions under pressure.

MEDIA OF HIGH REFRACTION AND SOME STANDARD MEDIA OF LOWER REFRACTION FOR THE DETERMINATION OF REFRACTIVE INDICES WITH THE MICROSCOPE

BY H. E. MERWIN[1]

(*Abstract*)

By weighing out and fusing together definite proportions of two or more suitable substances, immersion media, which become fluid by gentle heating, can be prepared, which remain permanently standard and cover practically the whole range of refractive indices of minerals. Fluid media covering the range 1.74 to 2.2 can be made from methylene iodide and its compound with arsenic trisulphide.

CERTAIN SO-CALLED METEORIC IRONS OF CANYON DIABLO

BY CHARLLES R. KEYES

(*Abstract*)

The great abundance of so-called meteoric iron found in the vicinity of Canyon Diablo, Arizona, has been pointed to as affording strong evidence of a

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[1] Introduced by Fred E. Wright.

meteor-impact origin of the remarkable depression a few miles to the eastward known as Coon Butte or Meteor Crater. On the recent visit to the locality during the transcontinental excursion of the American Geographical Society opportunity was afforded to inspect closely the occurrence of many of the "oxidized irons" found in the debris around the margin of the crater. Of sixteen samples collected of the unaltered kernels of these masses all proved to be simply ordinary hematite and not metallic iron, as claimed.

The instructive feature to be noted in this connection is that throughout the arid regions the small isolated iron-ore masses formed at or near the surface of the ground are not usually the hydrous iron oxide or limonite, as is the case in regions of moist climate, but the anhydrous minerals hematite and magnetite. Only under exceptional conditions when brought into contact with damp clays do the iron minerals change into the limonite variety.

There are still important finds of true meteoric iron in the neighborhood of Coon Butte, but the greater part of the materials passing as such are hematitic in character and not of celestial origin.

NEW OCCURRENCE OF MONAZITE IN NORTH CAROLINA

BY JOSEPH HYDE PRATT

(*Abstract*)

This paper describes an occurrence of monazite where the mineral is in crystals and masses, some of which weigh 60 pounds. Some of the crystals are well developed and are as much as 2¾ inches long. These crystals and masses of monazite are the largest the author has ever seen.

NEW OCCURRENCE OF PISANITE AND SOME LARGE STAUROLITES FROM DUCKTOWN, TENNESSEE

BY FRANK R. VAN HORN

(*Abstract*)

In an open cut at Isabella, near Ducktown, Tennessee, considerable amounts of a green and blue deposit of secondary origin were observed by the author in the summer of 1912. This was at first thought to be melanterite and chalcanthite, but a few tests and analyses have shown that the two substances are pisanite, with a varying percentage of iron and copper. The staurolite crystals are the largest ever seen by the writer. They are evidently entirely altered to mica and contain many inclusions of garnets.

SPECULATIVE NATURE OF GEOLOGY

BY W. M. DAVIS

(*Abstract*)

The opinion prevails in many places that geology is chiefly an observational science. This is not correct. It is chiefly a speculative science, in that the great body of its statements go far beyond the field of observable fact into the field that can be reached only by means of speculative mental processes. The recognition of this truth carries with it two important consequences: first, that more systematic and thorough instruction in the non-observational side of geology should be given in the educational preparation of young geologists for expert work; second, that the published work of trained experts should make more explicit distinction between the inferred conclusions that they reach and the observed facts on which the conclusions are based. The modern theory of coral reefs supplies an illustration of incomplete deduction and erroneous conclusion.

BEARING OF RECENT CLIMATIC INVESTIGATIONS ON GEOLOGICAL THEORIES

BY ELLSWORTH HUNTINGTON

(*Abstract*)

Under the auspices of the Carnegie Institution of Washington the author has for three years been engaged in the study of recent changes of climate in North America. His investigations have been directed not only to the dry portions of the United States, but to the tropical regions of southern Mexico and Yucatan, thus greatly increasing the types of climate from which conclusions can be drawn. A new method of investigating the climate of recent times has also been employed, namely, the measurement of the rate of growth of trees. From the Big Trees of California a curve has been constructed showing the fluctuations of climate for the past 3,000 years. A study of this curve and of other similar ones covering shorter periods, together with the observations made in the torrid zone, suggest certain hypotheses connected with some of the most important geological phenomena. One of these is the probable nature of the shifting of climatic zones which occurred during the glacial period. The phenomena of Yucatan seem to find their best explanation in connection with the theory of the development of glaciers in areas of permanent high pressure. More important than this is the marked agreement which seems to exist between climatic pulsations and changes in the number and intensity of earthquakes and volcanoes. The agreement of these phenomena, in both short and long periods, seems to point to a connection throughout geological time. This leads to a far-reaching theory of the connection between changes of climate, telluric movements, and some unknown force, perhaps of cosmic origin.

DISCUSSION

Prof. W. N. RICE: I perhaps misunderstood Doctor Huntington, but he seemed to me, in the introduction of his paper, to propose the problem of finding some one cause of oscillations of climate which would account both for oscillations of long and oscillations of short period. It seems to me probable that climatic changes are the result not of one cause, but of a complex of causes, and the dominant agency in oscillations of long period is very likely different from the dominant agency in oscillations of short period. Doctor Huntington has shown evidence which gives some degree of probability to the hypothesis of an unknown cause of climatic change on the earth, whose effect in the sun is shown by changes in sun spots. But there are other known agencies which must produce climatic change, though there may be difference of opinion as to their quantitative value. Elevation of land must produce local depression of temperature. Elevation of large areas to high altitudes must produce depression of mean temperature of the earth's surface. Increase of CO_2 probably must produce rise of temperature and increased humidity; decrease of CO_2 probably must produce contrary effects. These two agencies cooperate, since elevation of land must produce decrease of CO_2. Though we can not attribute to changes in the eccentricity of the earth's orbit the dominant influence claimed for it by Cross, it seems probable that great changes of eccentricity would produce some climatic effect. Climatic changes must be supposed to result from a complex of causes, some of which are known and others probably unknown.

Prof. C. W. BROWN: The question occurs to me that these curves—which, allow me to say, must represent an enormous amount of time and labor—that show approximate agreement at times between solar and terrestrial dynamic phenomena and terrestrial climate may have been partially obscured by mixing the data concerning seismic and volcanic phenomena of large land-masses, relatively stable, with those of smaller and less stable regions more susceptible to this unknown cosmic stimulus.

Smaller impulses would affect regions of the crust in a state of delicate equilibrium at once, yet they might affect more stable land-masses until the accumulated stresses resulted in rupture after a lag period of three, six, or many months later. A relatively feeble impulse of the waning portion of the period of activity might, therefore, serve as a trigger to set off the accumulation of strains in the more resistant segments. The maxima of the unstable areas might then be moved along or partially neutralized by the maxima of the larger, less easily affected areas occurring on the down slopes or at the minima of the former.

The difficulties resulting from lack of coincidence of the curves might possibly be avoided if the curves compiled from regions in unstable equilibrium were compared with each other, as well as those from more stable areas were studied separately. I feel diffident about bringing up this point and suggesting more labor, when it may have no value at all.

Dr. A. L. DAY: In general any pair of periodic curves may be combined in this way and will produce a series of maxima and minima in regular succession without proving anything more than their individual periodicity. In the pair of curves before us, from which strictly characteristic features have been removed by averaging, some independent proof other than the mere alternation of maxima and minima is, therefore, necessary to establish any relation between them.

PIEDMONT TERRACES OF THE NORTHERN APPALACHIANS AND THEIR MODE OF ORIGIN

BY JOSEPH BARRELL

(*Abstract*)

Physiographers are accustomed to build on the results of structural and historical studies in order to explain the origin of the present surface forms. Here the opposite method is followed—one which it is thought might be more widely adopted by historical geologists—building on a knowledge of the present relations of surface forms to rock structures in order to explain the past. In this first paper is given a description of the significant forms and the arguments as to mode of origin. In the second paper this data is combined with

stratigraphic and structural evidence to elucidate the post-Jurassic history of the region.

Students of the strata of the Coastal Plain have discovered numerous surfaces of unconformity in those deposits, indicating repeated retreats of the sea; but they have drawn their shorelines close to the present outcrops, thus expressing the conclusion that the oscillations of the strand have been essentially confined to the present coastal plain, including the portions now submerged. The geologist who has carried the evidence of the sea farthest inland is W. M. Davis, who showed from the character of the superimposed drainage that the sea had at one time advanced over the trap ridges of New Jersey onto the border of the crystalline highlands. In the present paper it will be argued, however, from additional lines of evidence that earlier invasions of the sea advanced much farther inland, the farthest reaching in fact to central Pennsylvania and western Massachusetts.

As bearing on the nature of the evidence for determining the limits of former marine invasions the address of Gilbert is recalled, delivered to the Geological Society December 30, 1892. In this it is noted that the present limits of sedimentary formations are primarily determined by the length of time which their outlying portions have been above baselevel, secondarily on the thickness, resistance, and original limits. It is seen, therefore, that the mere absence of Coastal Plain deposits from the higher slopes of the Piedmont Plateau or seaward slopes of the Appalachians raises no presumption either for or against the former presence of the sea over that region. If they had once been present they would now be absent. The problem must, therefore, be approached through other lines of evidence.

Difficulties are then noted in the explanation of the higher surfaces planed across resistant formations over certain parts of Pennsylvania, New Jersey, and Connecticut as remnants of a single peneplain of subaerial denudation, commonly spoken of as the Cretaceous peneplain.

As a preliminary step for the reexamination of the problem a statement of criteria is then given for determining with some accuracy where the evidence is preserved, the elevation of former baselevels of subaerial and submarine erosion. In addition to other criteria, it is shown that wind-gaps of a certain character cut through hard ridges give the best record of subaerial baselevels. The submarine plains are best discriminated through a determination of their shores. For such plains as are shown by various lines of evidence to be of marine origin the ancient levels are best determined from the marked accordance and flat tops of the remnants of the more resistant formations.

To detect by means of these criteria the existence of marine plains which have been uplifted and very largely destroyed by subaerial erosion a method of projected profiles is employed. This is applied to western Connecticut and Massachusetts, and brings to light the fact that the plateau sloping from the Green Mountains and Taconic Range to Long Island Sound is not a simple uplifted and dissected peneplain, but consisted originally of a flight of rock terraces, themselves somewhat sloping. The lower of these are relatively narrow and poorly developed, but preserve a considerable approximation to the original surface. The higher terraces, originally wide and flat, were successively raised and warped so long ago that they have been very largely destroyed. Certain intermediate terraces are the most unmistakable in their character, having been rather well developed and still preserving well characterized remnants. This series of terraces is shown to have been developed on the eastern side of the Appalachians over the whole region studied, from northern Massachusetts to the Potomac River. They have been named by the author in descending order from localities in western Massachusetts and Connecticut, where they are preserved in recognizable state. Their names and the approximate elevation of their inner margins in their type localities are as follows:

	Feet
Becket terrace	2,400
Canaan terrace	2,000
Cornwall terrace	1,720
Goshen terrace	1,380
Litchfield terrace	1,140
Prospect terrace	920
Towantic terrace	730

Lower terraces of less perfect development are also noted at the following elevations:

	Feet
Appomattox (Lafayette) terrace	500 to 540
New Canaan terrace	340 to 380
Sunderland terrace	200 to 240
Wicomico terrace	80 to 120

In regard to mode of origin these terraces are shown to still preserve in a measure the forms resulting from wave planation, the features of cliff and terrace developed across various structures and rock formations at right angles to the drainage system indicating that they cannot be reasonably ascribed to river erosion or subaerial denudation. The latter agencies, however, worked preparatory to the marine planation, and have in later time through their destructive effects largely masked the evidence of the former invasions and retreats of the sea.

Certain independent tests of these conclusions are derived from the drainage of eastern Pennsylvania and the finding of scanty gravels remaining at an elevation of 700 to 730 feet in Maryland.

The demonstration of the theses of this paper depend very largely on the maps and profiles shown in the stereopticon slides.

POST-JURASSIC HISTORY OF THE NORTHERN APPALACHIANS

BY JOSEPH BARRELL

(Abstract)

The previous paper develops the evidence of an alternating series of uplifts and strand lines. The present paper seeks to determine their place in geologic time by correlating them with the strata of the Coastal Plain. An outline of the results is as follows:

The dates of the piedmont terraces may correspond with those of certain formations of the Coastal Plain. The dates of the uplifts, on the other hand, should be marked by the intervening planes of unconformity; or, if the uplift did not reach the Coastal Plain, should correspond to intervening formations. Warping is shown to have progressed variably, but without reversal, during the periods involved. Thus physiography, stratigraphy, and structural geology give three converging methods for testing sequence and age—the province of historical geology. The several divisions of the science are interlocked and render mutual support.

The sequence of regional events during post-Jurassic time is shown to be determined with considerable probability as follows:

Comanche.—Intermittent interior uplift reaching large amount, marginal downwarping, and continental sedimentation.

Cretaceous (Upper Cretaceous).—The sea invades the Appalachians for the first time since the Paleozoic, but now from the ocean instead of the continental interior. At the maximum of transgression its waves cut the Becket terrace against the southeast side of the Green Mountains and the south side of the Catskills. This was followed by emergence of several hundred feet, a crustal stability for a considerable period, and the cutting of the Canaan terrace. Both of these terraces appear to be distinctly older than the following series; so that, as the next is probably Oligocene, these may be tentatively regarded as probably middle and late Cretaceous respectively.

Eocene.—Emergence of several hundred feet and retreat of the shore to the region of the present Coastal Plain. Long period of subaerial erosion.

Oligocene.—Probable date of submergence and development of the Cornwall terrace.

Miocene.—Emergence of several hundred feet. Erosion of inner portion of Oligocene from the Coastal Plain, followed by submergence of present coastal plain and edge of the present Piedmont Plateau either at end of Miocene or early Pliocene. No terrace recognized.

Pliocene.—Intermittent uplift and retreat of the sea; cutting of the Goshen, Litchfield, and Towantic terraces. The Appomattox (Lafayette) terrace, still preserving in part its surface deposits, is 200 feet below the Towantic and is probably late Pliocene in age. Below the Appomattox, or Lafayette, are the fainter Pleistocene terraces.

An uplift of a few hundred feet was all that was necessary at any time to cause a retreat of the shore from these high-level terraces to the region of the present Coastal Plain, since the present great difference in elevation is mostly due to later progressive warping. Similarly, intervening phases of slight submergence and crustal rest are sufficient to account for the planing inland by the sea. The sequence of events thus indicates progressive but oscillatory uplift during Tertiary time, becoming more rapid in the Pliocene and Pleistocene. The conclusions, as in the previous paper, rest largely on an analysis of the profiles.

DISCUSSION

Prof. D. W. JOHNSON pointed out that if we have an uplifted and tilted peneplain on which there are monadnock residuals, it is possible to select positions in which terrace profiles can be drawn similar to some of those on which Professor Barrell bases his conclusions in favor of marine planation. According to the theory of marine planation, what are now generally regarded as monadnocks are to be interpreted as stacks on the wave-cut plain, and should still show traces of marine cliffs. So far as the speaker has observed, this is not the case. Water-worn pebbles on the upland surface may be of stream origin as well as of marine origin, and hence special care is necessary to eliminate the possibility of stream origin before such gravels are accepted as a confirmation of the theory of marine planation. The speaker would also like to know whether Professor Barrell found the terrace levels to be horizontal over wide areas.

Prof. W. M. DAVIS: The introduction of a new view by a critical investigator, who thus traverses an earlier view that had gained general acceptance, is likely to lead us nearer to the correct interpretation of natural phenomena, particularly if the investigator himself had previously accepted the earlier view which he is now obliged to give up; and, as in the present case, the new view is based on facts not previously recognized and, indeed, in the earlier lack of topographic maps hardly recognizable. Hence on general grounds Professor Barrell's new interpretation of the uplands of southern New England seems more likely to be correct than my own earlier one.

As an additional test for the occurrence of a series of ancient sea cliffs in these uplands, let me suggest a search for "cliffs of decreasing height," particularly along the latest-made (lowest-standing) shorelines; for if a sea cliff is cut back over a distance several times greater than the diameter of the hills into which the background is dissected, and if the shoreline is many times longer than a hill diameter, a certain number of the hills must be transected by the retreating shoreline on the inland side of their summits, so that the cliff height must decrease with further recession. The absence of such cliffs—indeed, the prevailing absence of any cliffs—along the inner hilly border of the even uplands of Devonshire-Cornwall and of Brittany has led me to regard these uplands as uplifted peneplains of normal erosion, in spite of their nearness to the sea, and in spite of the occurrence on them of gravel patches with marine fossils. These are explainable by a brief submergence of the peneplain after it was degraded and before it was uplifted and dissected. On the other hand, the occurrence of cliffs, and especially of cliffs of decreasing height, along the inner border of an even upland would go far toward proving its marine origin. However, if the hills of the background were elongated ridges, cliffs of decreasing height would be rare or absent. The long and narrow ridges, which the inclined trap sheets of the Triassic area would soon form in an uplifted platform of abrasion, would be reduced to a lower level by sea action south of a shoreline, while retaining their former level little reduced north of the shoreline. As there are many shorelines and many trap ridges, it would seem probable that some of the latter should be transected by some of the former, and at the point of transection a sudden increase of height should occur independent of the fault-lines which traverse the trap ridges.

As to the inland reach of a primitive Chesapeake Bay far northward in Pennsylvania, the transverse course of the Susquehanna, where it escapes from the syncline of the Wyoming Valley, ought not, in my opinion, to be regarded as an example of superposition, for a river must somehow escape from a synclinal valley by a transverse course, whether it is superposed or not. Likewise, the longitudinal course of a stream, pointed out by Professor Barrell along the northern side of the west end of the Wyoming syncline, is as easily explained by adjustment to structure as by indirect effect of marine action.

An important question on which Professor Barrell did not explicitly state his opinion is: What was the form of the land area in which the sea cut the broad platforms and low cliffs that he describes as occurring at successively lower and lower levels? The land seems to have had a hilly or mountainous surface in the background, as has long been recognized in the description which treats the uplands of southern New England as an uplifted and dissected peneplain; and in the foreground there was a buried land surface of small relief, which the Potomac or some other formation still covers unconformably, this buried surface being an element that is common to both the earlier and the later view. But what sort of surface existed in the broad belt of country between the background, not invaded by the sea, and the foreground, still covered by stratified deposits? It seems conceivable that this intermediate belt, as well as the buried foreground, may already have had a moderate or small relief more or less interrupted by monadnocks, and a general slope to the southeast, when it was exposed to the attack of the sea; it may, indeed, have served in this reduced condition as the floor on which a heavy subsiding marine strata were laid down during the advance of the sea on the subsiding continent; and the advancing sea may have even then trimmed and shaved the subsiding land at successively higher and higher levels; and in this case the retreating sea has had, during each pause in its retreat, to clear away the inner extension of the overlapping strata before it could bench the underlying floor. But all this may have happened without producing a great amount of change in the form of the preexistent surface of the intermediate belt; and if thus interpreted, this belt might be called a sea-benched peneplain. If, on the other hand, the work of the sea was more profound, the resulting surface would be best described as a series of broad sea benches or platforms, separated by low cliffs.

Let me turn to another aspect of this problem. In the outline of method written on the blackboard in explanation of my paper, that preceded Professor Barrell's, there were certain headings of which no mention was made in my remarks. One of these, in the column of safeguards, was the word hospitality, which indicated the attitude that an investigator should strive to maintain toward all new theories, particularly toward such as may replace his own preferred view; for in this way he can best guard against the serious danger of favoritism. I confess freely that it is difficult immediately to take a perfectly hospitable attitude toward a new theory that will very likely be substituted for an earlier one of my own which I have held for more than twenty years with growing faith in its competence, but I propose to do my best to assume the proper attitude toward the new view, and hope that the recognition of the difficulty of this duty will make it easier. With hospitality should be associated responsibility. It is not appropriate for one investigator to leave to others the duty of testing any theory that enters into the solution of his problem; but here I do not expect my practice to equal my principle. It is not likely that I shall take up new field study of this problem; and the admirably fair and competent treatment that it is receiving from Professor Barrell, along with my abundant occupation at present in other directions, is my excuse. Revision of opinion is another safeguard against error; that I shall hope to make whenever need be; and under the lead of this heading Professor Barrell's paper, when printed, will receive the most attentive consideration.

Further, the capacity to do critical work implies training, and among the elements of training I would place much importance on the unpleasant experience of being compelled by the force of new evidence to give up an opinion that one has held for a year or more with satisfaction; for this shows the subject that his mind is really open to change when good reasons for change are found. Experience of this kind is seldom provided in systematic instruction. It does not often come from one's own intention. It is best supplied by the work of one's colleagues, to whom one ought therefore to feel grateful as occasion offers. But gratitude of so dutiful a kind may well be accompanied by a certain amount of personal discomfort. It would not be sincere on my part to say that gratitude in this case is an unmixed feeling. The case resembles that of a patient who swallows his medicine, in spite of its unpleasant taste, because he has confidence in his physician. There is no one among our members from whom I, as a patient, would more confidently swallow an unpalatable dose in the expectation of its leading to a cure than from Dr. Barrell.

Mr. N. H. **Darton**: I have given much attention to the physiographic development of the Piedmont slope in Maryland and Virginia and do not feel convinced that the region shows evidence of having been planed or terraced by the ocean. It seems more likely that the features described by Dr. Barrell are parts of slopes representing various stages of subaerial planation of Tertiary and later times. In a few places to the eastward there was some incursion of the sea during Chesapeake time, and there was extensive deposition of Lafayette and Pleistocene formation and later deposits, most of which have since been removed. I should mention in this connection that the Lafayette and Pleistocene deposits near the western margin of the Coastal Plain are not of marine origin, but are fluviatile and estuarine products.

In general it is unsafe to regard rounded hills of similar height as representing a terrace, for such hills are in process of degradation, and since Tertiary and early Pleistocene times have greatly decreased in altitude, and the approximate coincidence in height of scattered hills of hard and of soft rocks does not necessarily define a terrace.

Professor **Barrell** replied as follows: Dr. Leverett has asked what relation the Hudson gorge may hold to the Sunderland terrace. In reply, I would say that this investigation shows no new facts on which to base a relationship. It is thought from glacial erratics dropped by floating ice on the Coastal Plain of Maryland that the Sunderland terrace was covered by the sea during an early epoch of glaciation. The terrace as shown on the Connecticut shore has been largely destroyed by erosion, yet fragments remain sufficiently intact to show level tops and integrate into an even sky line. Therefore a continental glacier was not here at the time of wave planation. The subaerial erosion features now submerged below present sealevel can be divided into the mature valleys which now constitute such drowned areas as Long Island Sound and Chesapeake Bay and the deep and narrow inner gorges. From the degree of their physiographic preservation these features do not impress one as older than the Sunderland terrace, so that the suggestion from this comparison is for a Pleistocene age.

Prof. D. W. Johnson has raised several points. First, in regard to the significance of gravels found on terraces. As Professor Johnson points out, the mere presence of such gravel is in no sense a criterion of marine as opposed to fluviatile origin. But when taken into connection with the size of pebble and the relations of the terrace to the highlands behind, then such gravels may become of significance. Bonney has shown that Alpine rivers of moderate length carry pebbles from four to six inches in maximum diameter up to distances of twenty miles and more from the Alps, over the Piedmont. On these Maryland terraces no such relations of mountains and grade existed as would give the rivers such carrying power. The gravels were found in scattered pebbles up to six inches in diameter on the highest remnants of a flat plain facing the sea and not within valley walls. Neither is the general height of the country behind such as could account for the presence of gravel of this size.

Professor Johnson speaks further of the possibility of fitting certain assumed terraces to any part of an irregular profile. Again, as an abstract proposition Professor Johnson makes a good point, but one which has been abundantly guarded against in this investigation and which is ruled out by the evidence. The terraces up to the 1,700-foot level are sufficiently well preserved over certain regions to give a markedly level sky-line, and these levels can be detected at intervals on resistant formations along hundreds of miles of the Atlantic slopes. The two higher terraces are less well preserved, and the conclusions in regard to them rest therefore not so much on their internal evidence as from the broader relations of these terraces, on the one hand, to the well-preserved ones at a lower elevation on the seaward side and, on the other hand, to the different character of the topography on the side of the mountains, especially the sharpness of that line diagonal to the structure which separates the highest terrace from the still higher and mountainous uplands.

Professor Johnson has spoken also of the distinction in form which should show between monadnocks and rock-stacks. These distinctions are largely features which would be lost long before the residuals had themselves disappeared. On the higher terraces the long exposure to subsequent subaerial activities has smoothed down all slopes, whatever their origin, to such grades as are in adjustment with the later history.

Mr. M. R. Campbell has spoken of the different degree of warping which would be implied in consequence of the acceptance of these terraces as surfaces of marine planation. It is true that if these be accepted, since they are greater in number than the baselevels previously used, it would mean a review of the correlation of the baselevels of the continental interior and would probably require the assumption of less warping in a new interpretation. On the interior slopes of the Appalachians the erosion has been presumably entirely subaerial, but the higher levels were largely developed on softer formations than where they are preserved on the Atlantic slope, with the result that subaerial peneplanation may there have been better developed, with the consequences in drainage history which have been previously held.

Mr. Darton has suggested that we do not know how much erosion has served to lower any particular hill and consequently that there is doubt thrown on the reconstruction of ancient terraces by the method of projected profiles. In answer, it should be stated that such a hypothesis must, of course, be in the geologist's mind in looking at every region, but that it may be readily tested in any region by the evidence of the field. When a plain is elevated and subjected to erosion, for a time there will be traceable a marked accordance between the level of the higher hilltops; but as all lose a part of their initial elevation, there will arise a maximum discordance of the higher summit levels. This will mark advanced maturity in the erosion cycle. In old age a new accordance will slowly become developed in relation to the lower and younger baselevel. The test, then, of the amount of loss by erosion suffered by the highest remnants of an old marine plain is the degree of accordance of the highest residuals—an accordance to be traced across the strike of resistant rocks and thus shown to be independent of structure. This criterion has been applied from New England to the Potomac River and indicates that it is still possible to rather closely determine the levels of even the terraces most destroyed.

Mr. Darton has mentioned that the Sunderland was largely an estuarine formation. It may also be so regarded in Connecticut, since Long Island must then have existed as a partial barrier to the open sea. Furthermore, all the Pleistocene terraces show the marked character of lapping around headlands, indicating that the land did not stand still sufficiently long after a stage of subsidence for shore erosion to produce a mature shoreline.

Professor Davis has made the point that the slopes of the hills partly consumed by sea erosion should be steeper facing the sea than on the landward side. It would seem that this criterion should be susceptible of application to the Pleistocene terraces, though the initial slopes may be somewhat masked by the effects of glaciation. The test must, however, be made in the field rather than from maps, since these New England maps are in general not faithful enough in regard to the details of slope to enable them to be used for such refined discriminations.

RECENT CHANGES IN THE ASULKAN GLACIER

BY HEINRICH RIES

(*Abstract*)

The Asulkan Glacier is located four miles south of Glacier Station, in the Selkirks of British Columbia. Observations made on it between 1908 and 1912 show that it receded rapidly during the first part of this period, but not as much during the latter part. Photographs taken from the same point in successive years bring out these changes clearly.

EVIDENCE OF VERY EARLY GLACIATION IN OHIO

BY GEORGE D. HUBBARD

(*Abstract*)

1. Introduction: Summarizes the results of earlier workers.

2. Early drift: Describes and discusses some very old drift deposits in Hocking, Ross, Pike, and Jackson counties.

3. Stream diversions: Describes diversions of various ages. Some of these are quite recent and seem to be connected with the Wisconsin ice-invasion; others are much older and may represent different stages of development,

hence possibly more than one ice-invasion. Some valleys made by diverted streams were considerably mature when Illinoisan outwash was laid in them.

4. Theories offered for explanation of diversions.
   - (*a*) Diastrophic tilting and adjustments.
   - (*b*) Spring work and headward erosion.
   - (*c*) Varying strength of strata open the way for diversions.
   - (*d*) Ice-invasions.
5. Conclusions.

BEGINNINGS OF LAKE AGASSIZ

BY FRANK LEVERETT

(*Abstract*)

The position and extent of the Milnor Beach and the correlative outlet and the moraine marking the position of the ice-border have been determined and studied the past season. It was also found that an outlet of Lake Agassiz farther west than Lake Traverse was in operation in the Herman and Norcross lake stages. The Lake Traverse outlet alone was in operation during the Timpah and Campbell lake stages.

Water-laid moraines within the limits of Lake Agassiz have been mapped as far north as the latitude of Fargo and Morehead. They show a strong lobation of the ice-sheet in the Red River basin.

REMARKABLE DEFORMATION OF THE ALGONQUIN BEACH

BY FRANK LEVERETT

(*Abstract*)

Levels run by the writer in 1912 along the Algonquin Beach in the northern peninsula of Michigan and on Saint Josephs Island have shown the deformation to be irregular, with a range from 2 feet to 10 or 11 feet per mile in the direction of maximum uplift, slightly east of north. There is not a constantly increasing rate of rise, but less rapid follow more rapid rates.

DISCUSSION

Prof. J. W. G'LDTHWAIT: A profile of the Algonquin Beach in Ontario made in 1907 is very similar to the one shown here by Mr. Leverett, except that the abrupt increase in tilt rate from 4 feet per mile to 6 feet comes here at an altitude of about 800 feet and in Ontario at 847 feet.

The discordance among the points which Mr. Leverett's profile shows is too great to be accounted for by original irregularities alone or by errors in measurement; they appear to be explicable only by inequality in the upwarping.

PLEISTOCENE SUCCESSION IN WISCONSIN

BY SAMUEL WEIDMAN

(*Abstract*)

A brief statement was given concerning present knowledge of the drift and associated surface deposits in Wisconsin, with a map showing distribution of

the formation. There appear to be five drift sheets exhibited in Wisconsin as follows:

First drift, a very old, thin drift; second drift, a very old, thick drift, correlated with the Kansan of northeastern Iowa; third drift, a relatively old, thin drift, correlated with the Iowan of northeastern Iowa; fourth drift, a relatively thin, fresh drift, correlated with the early Wisconsin of northeastern Illinois; fifth drift, the Wisconsin drift. Extensive alluvial and lacustrine deposits in old valleys and lowlands of interglacial origin between the second and third drifts; the loess deposits of later origin than the third drift and older than the fourth.

IOWAN DRIFT

BY FRANK LEVERETT

(Abstract)

Dr. S. Weidman, of the Wisconsin Geological Survey, has found in western Wisconsin an old drift sheet overlying the Kansan drift and extending in places beyond its limits, whose state of weathering is about that of Illinoisan drift. Its constitution there is unlike the underlying Kansan, and it lies in and partially obliterates valleys of post-Kansan age. It has loose texture and much gravelly material, and is so rapidly pervious to water that it has in places suffered very little erosion and presents intact the features left by the ice-sheet. It is thought by him to be a continuation and correlative of the Iowan drift of northeastern Iowa.

Drift of this sort has been noted by the present writer and by Doctor Weidman in Minnesota inside the limits of the Kansan drift; also in southern Wisconsin and northwestern Illinois east of the Driftless Area, either overlying or extending outside the typical Illinoisan drift. Its southern limits as fixed by the present writer are at the Green River Basin in western Illinois, there being typical Illinoisan farther south.

This drift is not markedly different from Illinoisan in degree of weathering, but differs from it in being more irregular in composition and more varied in topography and depth. It includes the pre-Wisconsin eskers and kames of northwestern Illinois and southern Wisconsin, and yet over wide areas is a very scanty deposit. Similarly it includes the gravelly knolls of southeastern Minnesota that obstruct the post-Kansan drainage lines.

The so-called Iowan drift may stand in about as close relation to the Illinoisan as do the later Wisconsin moraines to the earlier Wisconsin. It does not seem to be separated from the Illinoisan drift by a definite interglacial stage, but instead to represent a substage or stadium of the Illinoisan. It may, therefore, be advisable, pending further study, to apply to it the double name Later Illinoisan or Iowan.

DISCUSSION

Prof. A. P. COLEMAN: The name Keewatin is pronounced Keeneâytin and not Keewattin. Was there not a migration of the glacial center from the Keewatin area west of Hudson's Bay to the Patrician area, to coin a term from the name of the new district of Patricia, and finally to the Labrador area?

There are older striæ running south in regions to the northwest of Lake

Superior, partly removed by later glaciation from the northeast, confirming Mr. Leverett's idea of a movement of ice southward from the Patrician region, causing the Iowan till sheet.

CANYON AND DELTA OF THE COPPER RIVER IN ALASKA

BY LAWRENCE MARTIN

(*Abstract*)

The canyon by which the Copper River crosses the Chugach Coast Range in Alaska is over 100 miles long and 4,000 to 7,000 feet deep, the width varying from 2½ to 4 miles. The heights specified are attained within 1 to 3 miles of the river. The Copper River Canyon is, therefore, deeper in places than the Grand Canyon of the Colorado, with which it forms numerous contrasts because of profound glacial erosion. At its northern end is Wood Canyon, which is apparently due to postglacial incision following glacial diversion of the Copper River, rather than rejuvenation through warping, as postulated by Spencer. The former Copper River Glacier widened and deepened this canyon tremendously, as is shown by oversteepened valley walls, truncated spurs, and hanging valleys. The grade of the river in the canyon is 3½ to 15 feet to the mile. The canyon terminates in a flaring lower section interpreted as a former fiord, now filled by the glacial sediments of the Copper River delta, whose area exceeds 500 square miles. On this delta detailed measurements of width and depth and of the rate of stream flow in the several distributaries furnish important data on the carrying power of glacial streams. Comparative studies in several years show the rates of deposition and of erosion. Borings by the railway engineers show the nature of outwash material below the surface at several positions and depths on the delta. Vegetation below present sealevel in these borings proves recent sinking of the land. The existing glaciers of the Copper River Canyon dominate the river in places, causing the deposition of outwash gravels in one area of over 50 square miles above a glacier dam. The distribution of present-day vegetation in the canyon suggests a recent prehistoric period of glacial expansion.

SUBMARINE CHAMÆCYPARIS BOG AT WOODS HOLE, MASSACHUSETTS, AND ITS RELATION TO THE PROBLEM OF COASTAL SUBSIDENCE

BY DOUGLAS W. JOHNSON

(*Abstract*)

At Quamquisset Harbor, near Woods Hole, the sea has cut into a chamæcyparis bog, the base of which is 13 feet below mean sealevel. This submarine bog has been regarded by some as an especially good proof of recent coastal subsidence, and therefore deserves special attention. According to Bartlett,[1] the bog occupies a kettle hole, and represents successive layers of vegetation continuously built up to the surface of a ground-water table which rose higher and higher as the land subsided. This subsidence required something over 2,000 years, and is still in progress, the sea having recently cut into the bog

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[1] Rhodora, vol. xi, p. 221; Science, vol. xxxiii, p. 29.

deposit. The argument depends on four assumptions: (1) The bog formed in a kettle hole, not open to the sea; (2) the chamæcyparis stumps occur in place from the bottom to the top of the deposits; (3) coastal subsidence is the only theory competent to explain such a succession of stumps in place; (4) the lower as well as the uppermost layers of the deposit are of recent date (that is, formed within the last two or three thousand years). Evidence is presented to show that the validity of each of the above assumptions must be questioned. It is believed that the bog at Woods Hole affords no evidence either for or against the theory of recent coastal subsidence.

CONTRA-IMPOSED SHORELINES

BY CHARLES H. CLAPP [1]

(*Abstract*)

By the retrogression of a soft mantle covering hard rocks a shoreline, which during an earlier portion of a marine cycle was a simple, cliffed, mature shoreline, may be brought or "placed against" the underlying hard rocks. The resulting shoreline will be irregular and in a very young stage. Such a shoreline is analogous to the valley of a superimposed river and is called a "contra-imposed" shoreline. The development of contra-imposed shorelines near Victoria, British Columbia, is described.

PEAT DEPOSIT OF GEOLOGICAL INTEREST NEAR NEW HAVEN, CONNECTICUT

BY CHARLES A. DAVIS

(*Abstract*)

Ordinary peat deposits in the glaciated regions of the United States are of little interest to geologists compared with those of northern Europe, since they are in most cases superposed on the late Wisconsin drift. They thus represent a time too short to record many changes in climate or flora.

Near New Haven, in the marshes of Quinnepiac River, is a deposit of excellent brick clay, presumably of glacial origin, over which is superposed a peat bed of varying thickness. The removal of the peat to work the clay bed by the brickmakers has exposed large sections of peat which afford opportunities, unusual in the United States, for studying the history of the beds.

In a typical section at the brickyard near "Schützer Park" the peat rests on a thin bed of gravel or sand, on top of which is a forest soil bed, in which there are stumps of trees whose roots penetrate the underlying gravel. Above this woody stratum the peat shows flora changed gradually from forest to fresh-water sedge marsh, then to brackish, and finally to salt marsh. The stump-bearing layer is now several feet below the tide level of the undisturbed marsh. The clay below the gravel has numerous woody roots much older than those in the gravel.

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[1] Introduced by D. W. Johnson.

EARLY PALEOZOIC PHYSIOGRAPHY OF THE SOUTHERN ADIRONDACKS

BY WILLIAM J. MILLER

(*Abstract*)

Some of the more important points regarding the southern Adirondack region brought out in this paper are the following:

1. The early Paleozoic sea encroached on a more or less well developed peneplain in the Adirondack region, this peneplain being moderately rugged in the northeastern and eastern portions; less so in the southern portion; and very smooth in the southwestern portion, such a difference in character of the peneplain no doubt being due to the fact that the southwestern portion longest remained above sealevel.

2. When the early Paleozoic sea encroached on the region it did not set up embayments or estuaries in the pre-Cambrian rock area, except possibly to some extent on the eastern side, as shown by the peneplain character of the pre-Cambrian rock surface, the typical marine character of the deposits in the Paleozoic rock outliers, and the downfaulted structure of the outliers.

3. The region was never completely submerged during the Paleozoic era, though at the time the maximum submergence during the Trenton a comparatively small land-mass remained.

4. The land areas varied considerably in extent from time to time, but the principal area of unsubmerged pre-Cambrian rock ran in a northeast-southwest direction through the southern Adirondack region and most likely continued through the northern region.

5. This prominent northeast-southwest structural belt or axis of elevation, occupying practically the same position as the present main axis of elevation of the mountains, has played an important part in the geological history of northern New York.

LEVEL OF MAXIMUM PRECIPITATION AS A FACTOR IN THE GLACIATION OF MOUNT RAINIER

BY F. E. MATTHES[1]

(*Abstract*)

A study of the present distribution of ice on Mount Rainier and of the sculptural features indicative of the former extent of its ice cover seems to warrant the inference that that mountain carried on its broad summit but little, if any, more snow during the last glacial epoch than it does today. On its flanks, however, the ice was formerly much thicker than now, while the profound valleys radiating from its base were occupied by glaciers of considerable extent. But these great ice-streams were not merely prolongations of the swollen Rainier glaciers. As the topography about the base of the volcano indicates, they originated independently at relatively low levels, for the most part in cirques, at altitudes between 4,000 and 6,000 feet—at the same levels, in other words, at which the other valley glaciers of the last Glacial epoch had their origin throughout the Cascade Range. The Rainier glaciers, therefore, were

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[1] Introduced by M. R. Campbell.

only good-sized tributaries to them, in many instances no larger than the ice-masses contributed by cirques on neighboring mountain crests.

The explanation of this relative paucity of ice on the cone of Mount Rainier during the last glacial epoch is sought in a lowering of the level or zone of maximum precipitation concomitant with the depression of the isotherms. The level of maximum precipitation is estimated to lie at present between 8,000 and 10,000 feet, or, roughly, 5,000 feet below the summit of the mountain. The prevalence of maturely developed cirques of large capacity at altitudes between 4,000 and 6,000 feet, not only in the immediate vicinity of Mount Rainier, but throughout a large portion of the Cascade Range, taken together with the absence of evidences of a former proportionate increase in the volume of the ice-streams on the cone of Mount Rainier, points strongly to the probability that during the last glacial epoch the level of maximum precipitation was depressed to altitudes between 4,000 and 6,000 feet.

The cone of Mount Rainier, accordingly, rose high above this zone of deep snows into atmospheric strata of relative aridity, and this no doubt was true of the other lofty volcanoes of the Cascade Range.

CHARACTERS OF THE OLDER SECTIONS OF THE NIAGARA GORGE AND THEIR CORRELATION WITH GREAT LAKES HISTORY

BY FRANK B. TAYLOR

(*Abstract*)

In his studies in the Niagara région a number of years ago Dr. G. K. Gilbert found that the first flow of Niagara River poured over the escarpment at five different places, the present place being the most westerly. Obviously, the river discharged only a fractional part of its volume through any one channel, and yet three of the channels east of Lewiston indicate large volumes. Altogether the several channels show that the total volume was nearly if not quite as large as at present and certainly several times larger than the discharge of Lake Erie alone.

In the Great Lake history it is found that the first flow of Niagara River carried not only the discharge of Lake Erie, but also that of Early Lake Algonquin. The latter lake covered the south half of Lake Huron, and though receiving nothing from Lake Michigan or Lake Superior, received a large contribution from the east from the region of Georgian Bay and Lake Simcoe and the ice-sheet north of them; but this arrangement of drainage was short lived. It ended when the retreat of the ice-sheet opened the outlet at Kirkfield, Ontario, for this outlet immediately carried off the whole discharge of the upper three lakes, leaving Niagara with only the discharge of Lake Erie, which is approximately 15 per cent of Niagara's present volume. There is abundant proof that this arrangement lasted for a relatively long time; but it was finally brought to a close by a great uplift of northern lands, which raised Kirkfield above the level of Port Huron and sent the discharge of the three upper lakes to Lake Erie and Niagara.

These three stages of the Great Lake history are clearly defined. Where are their correlatives in the Niagara gorge?

Spencer, with a different conception of the lake history, attributes the entire stretch of gorge from its mouth up to the head of Foster's Flats to what he calls the "Erie Stage," meaning by that that the river carried only the discharge of Lake Erie throughout this whole time. But his interpretation ignores entirely two well established stages of the lake history.

There are characters in the Niagara gorge which appear to correlate perfectly with the three lake stages mentioned above. Ignoring the older basin of the Whirlpool and beginning at the upper side of the Eddy Basin (lower end of the gorge of the Whirlpool rapids), the gorge from there to its mouth is divisible into three sections on the basis of characters indicating variations of volume. The newest of these sections extends from the upper side of the Eddy Basin to the bend of the river just below Niagara University and is known as the Lower Great gorge, for its cross-section corresponds to that of the Upper Great gorge now being made, and its place among the other sections corresponds precisely to the Port Huron stage of Lake Algonquin, when Niagara had the full discharge of the four upper lakes.

The remainder of the gorge to its mouth comprises the two earlier sections and must, therefore, include the gorge correlative of the Kirkfield stage, which endured a relatively long time and during which Niagara carried only the discharge of Lake Erie. But this section can not be supposed to extend all the way to the mouth of the gorge, for beginning at that point there must be a section extending at least a short distance southward, which is the correlative of Niagara's first flow, when the volume of the river was divided between five points of discharge over the escarpment. The line of division between this first or earliest section and the succeeding longer section which corresponds to the Kirkfield stage is not so clear as might be desired, for the whole gorge below the university has been subjected to important modifying conditions, which have obscured very considerably the characters originally given to that part when it was made. Among these modifying conditions are: (1) changes of level of both lakes Iroquois and Ontario; (2) thinner beds of the capping Lockport limestone; (3) greater thickness of shale in the gorge wall, and (4) longer time of weathering.

It is believed, however, that the division point between the first or oldest two sections is indicated with considerable clearness at a point about 2,000 feet south of the mouth of the gorge. North of this point the alinement of the cliffs is somewhat irregular and the average top width is approximately 1,400 feet. South of the division point the cliffs are remarkably straight and parallel as far as the bend just below the university, and the average top width is close to 1,300 feet. Only at one place, about opposite Smeaton ravine, does this part of the gorge bend out of a straight line. For about 2,000 feet above its mouth, therefore, the gorge appears to be the correlative of Early Lake Algonquin and the period of first and divided flow of the river. The remaining portion southward to the university is the correlative of the Kirkfield stage of Lake Algonquin, when Niagara carried only the discharge of Lake Erie. This section of the gorge was therefore narrow, like the gorge of the Whirlpool Rapids, when it was first made, though its top width is now nearly twice as great. The history found for this second section agrees in the main with Spencer's interpretation, but the other two sections do not, for they both require large volume for the river.

The paper is devoted mainly to a discussion of the history and modifying conditions which have affected these older parts of the gorge and made so difficult their correlation with the lake history.

MICROSTRUCTURE OF TITANIFEROUS MAGNETITES[1]

BY JOSEPH T. SINGEWALD, JR.

(*Abstract*)

A study of etched polished surfaces of titaniferous magnetites shows that they consist in part of granular aggregates of magnetite and ilmenite. A microscopic investigation of the magnetite grains reveals further that the latter are not homogeneous. but contain countless minute intergrowths of ilmenite. This paper described the nature of these intergrowths.

ORIGIN OF GRANITES AS WELL AS METACRYSTALS BY SELECTIVE SOLUTION—A RECANTATION

BY ALFRED C. LANE

(*Abstract*)

Metamorphic rocks having been exposed to increased temperature and pressure will not only be recrystallized, but any included moisture will have its solvent power increased. Slowly this solvent power will diminish, after the main metamorphic action has taken place. and the pressure is compressive rather than differential as the strata return to the pressure and temperature at the surface. It is at this time that the main metacrystals, chloritoid, staurolite, etcetera, are formed. If a sandstone bed containing a large amount of water, inclosed in slates, like the Berea Grit, were put through the same process, there seems no reason why a very large amount, or the whole of the rock material, should not be dissolved and be reprecipitated, either as the whole mass of strata came nearer the surface or as the dissolved stratum was enabled by fissures to find its way to places more favorable to crystallization. Such rocks are likely to be near a eutectic granite in composition and pegmatitic in texture. The writer did not believe that such rocks existed, but is now inclined to believe that some of the Maine pegmatitic granites may be of this nature.

DISCUSSION

Dr. G. P. MERRILL remarked that he had seen the rock in outcrops along and in the road running south toward Spruce Point. He had noted the close parallelism of the feldspars and also the apparent increase in schistosity parallel with the walls in proximity with its contact with the granite. He questioned if the structural peculiarities were not due to a shearing from crustal movements during the cooling and gradual stiffening of the magma.

PRE-CAMBRIAN STRUCTURE OF THE NORTHERN BLACK HILLS, SOUTH DAKOTA, AND ITS BEARING ON THE HOMESTAKE ORE-BODY[2]

BY SIDNEY PAIGE

Published as pages 293-300 of this volume.

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[1] Read with the permission of the Director of the U. S. Bureau of Mines.

[2] Presented at the meeting under the title "Pre-Cambrian structure of the northern Black Hills as bearing on the origin of the Homestake ore-body."

DISCUSSION

Prof. J. D. IRVING: The remarks just offered by Mr. Sidney Paige on the Homestake ore-body have been of considerable interest to me, as it was my good fortune to make an examination and publish a report[2] on the Homestake ore-body some 15 years ago. I am not very familiar with the broader structure and lithology of the rocks which inclose the ore-body, in so far as they were observed underground during the very brief study which I was able to make, permission to enter the mine having been withdrawn by the management shortly after the beginning of my field work. The surface geology was done by Professor Jaggar and his assistants, so that I am unable to comment on the structural features mentioned by Mr. Paige.

A very large collection of specimens of the ore, however, was made on all levels of the Homestake mine, extending to a depth of approximately 900 feet. These represented all varieties of ore found in the Homestake mine, and I was able to make from them a rather complete petographic study, the results of which, to a large extent at least, seem to me to make this explanation improbable.

The most notable feature about the Homestake ores is that they exhibit no lithologic or textural features which seem to distinguish them from the barren country rock; so well has this feature been recognized that the company has never been able to distinguish the ore without either panning tests or assays. When we first took up the study of the Black Hills ores, we noted that through some of the rock which carried the gold pyrite, pyrrhotite and subordinate arsenopyrite occurred in considerable abundance. In other varieties this was accompanied by quartz, and in some stopes the ore was largely made up of the silicate Cummingtonite, which was, I believe, first recognized by Mr. W. Lindgren. In still other varieties dolomite was observed in considerable quantities and after red garnet, presumably of the variety pyrope. In all of these varieties of ore the appearance of the rock was apparently characteristic. Such ore, however, represented only a small part of the ore mined. The larger part of it was simply silicon schist containing no carbonates and in no respect different from the non-auriferous schist. Such ores were simply mica schist, schist, quartz schist, chlorite schist, and other varieties of non-calcareous schists and metamorphic rocks, whose only distinction from barren country rock lay in their containing small quantities of gold. Careful microscopic study yielded no indication of extensive alteration of any kind and showed no tectural or mineralogical features which were not also observable in the unmineralized rocks.

In addition to this, no evidence of replacement was discernible and the ores passed insensibly into barren rock. While, therefore, Mr. Paige's hypothesis as to the origin of these ores by replacement of calcareous members in the Algonkian group may be of limited application in a few of the ore-masses of the mine, it certainly is not applicable to the major portion of those ores examined by myself. Since these constituted a very complete and representative series of all of the ores there exploited, I feel that Mr. Paige's hypothesis of origin by replacement of calcareous rocks is, to say the least, highly improbable.

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[2] Professional Paper No. 26, U. S. Geological Survey.

PETROLEUM FIELDS OF NORTHEASTERN MEXICO BETWEEN THE TAMESI AND TUXPAN RIVERS[1]

BY I. C. WHITE

Published as pages 253-274 of this volume.

DISCUSSION

MR. F. W. DE WOLF: This is the first time I have learned of the occurrence of petroleum in close relation to igneous rocks. The matter is especially interesting to me because of the occurrence in southern Illinois of igneous dikes which rise through formations which in adjourning counties yield petroleum.

I recently learned of a coal mine in which the coal is partly coked by a dike and in which there is said to be considerable gas. The gas is apparently not methane, but, at least to a large extent, hydrogen sulphide, which may have come from a lower oil-sand.

INADEQUACY OF THE SAPROPELIC HYPOTHESIS OF THE ORIGIN OF COAL

BY EDWARD C. JEFFREY[2]

(Abstract)

Potonié in particular has maintained that certain coals designated sapropelic, laid down under open water, are largely composed of the structural and chemical remains of Algæ. It is clear, as the result of the employment of improved methods of investigation, that the structural elements in question are not Algæ at all, but the spores of extinct Vascular Cryptogams. It is further claimed by Potonié that coals of dull and waxy appearance and conchoidal fracture alone belong to the group of subaqueous coals and that coals presenting alternating bands of dull and bright substance represent successive epochs of terrestrial and aquatic deposition. This German authority likewise maintains that coals entirely bright in appearance and of more or less prismatic fracture are of exclusively terrestrial or humic origin; or, in other words, represent the consolidated remains of former peat bogs. The purpose of the present communication is to show that no adequate idea of the structure and mode of formation of coals can be obtained from geological evidence alone. Thin sections prepared by modifications of biological methods make it quite clear that the dull or bright appearance or conchoidal or prismatic fracture of coals presents no reliable index of their composition and mode of formation. Accompanying photomicrographic illustrations make it obvious that nearly all coals, contrary to almost universally accepted opinion, have been formed under open water and very few indeed terrestrially as peat bogs or accumulations of humus.

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[1] Presented at the meeting under the title "Gulf Coast petroleum fields of Mexico between the Tamesi and Tuxpan rivers."

[2] Introduced by David White.

WATER AND VOLCANIC ACTIVITY[1]

BY ARTHUR L. DAY AND E. S. SHEPARD

Published as pages 573-606 of this volume.

Discussion

The author replied to questions by W. M. Davis, R. A. Daly, J. F. Kemp, and E. Howe as follows:

(Davis.) Small but unmistakable pale blue flames of burning sulphur can be seen at night during any period of considerable activity; similarly a pale blue flash following the explosion of a bubble, though with greater difficulty.

(Daly.) The position of "Old Faithful" is somewhat variable when the banks are falling in, following a receding lava column—perhaps due to partial choking of the opening below.

(Kemp.) Water above its critical temperature will circulate exactly like any gas—percolate slowly through porous media, mix (or reach) with other gases, etcetera.

(Howe.) The bowl about the liquid lava, and in fact the entire island of Hawaii, is porous and meteoric water falls on it. It is therefore not possible to say that the lava has no meteoric water, but the probability of meteoric water entering the lava near the surface is small.

GEOLOGIC SECTION OF THE PANAMA CANAL ZONE

BY DONALD F. MAC DONALD[2]

(*Abstract*)

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Rock Succession of the Isthmus.

General Statement

Within the Canal Zone are eleven distinct groups or formations of what may broadly be designated as bedded rocks. There are also six broad rock groups of igneous origin. Of the former the oldest two formations contain no fossils, so their age is unknown. The lower part of the Bohio conglomerate is also of unknown age. The other formations range from Lower Oligocene to late Pleistocene. The Miocene is, so far as known, not represented in the rock succession. Correlation across the Isthmus is a difficult matter because of sparsity of outcrops; hence further work may slightly modify the conclusions reached herein.

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[1] Presented at the meeting under the title "Preliminary report of certain physical and physiochemical observations at the Kilauea crater."

[2] Introduced by James F. Kemp.

NUMBER 1. BAS OBISPO FORMATION

The Bas Obispo formation, the oldest Isthmian formation so far known, and probably of pre-Tertiary age, is a volcanic breccia with some local meta-conglomerate of andesitic composition. It outcrops extensively at Bas Obispo and near Old Panama, and small outcrops rise above the alluvium near Miraflores and Diablo Ridge.

NUMBER 2. LAS CASCADES AGGLOMERATE

The Las Cascades agglomerate overlies the basal breccia and outcrops extensively along the canal between Empire and Las Cascades. It consists of greenish to gray basic agglomerate, which contains large and small subangular fragments in a fine-grained ground-mass of volcanic clay and tuff. The whole is arranged in massive to roughly bedded unconformable deposits, interbedded with which are andesitic flow breccias, some fine-grained grayish and some coarse-grained dark andesitic flows, and a few easily crumbled lava mud flows which show columnar jointing where exposed in the canal. The whole is cut by large and small basalt dikes.

NUMBER 3. BOHIO CONGLOMERATE

The Bohio conglomerate consists of two members. The lowermost of these is, so far, of indeterminable age, but seems to be considerably younger than the Las Cascades agglomerate. It consists of gravel, cobbles, and boulders up to several feet in diameter, fairly well bedded, but locally massive. Interbedded with the coarser material are sandstone and argillite layers. The uppermost member is of the same general composition, but contains some beds of dark gray foraminiferal marls probably of early Oligocene age. The cobbles and boulders in both formations are cherts, andesites, and diorites in composition, and were derived from the older intrusive masses of igneous rock, now found at intervals along the central part of the Isthmian region. The formation is probably nearly 1,000 feet thick, and it outcrops extensively in the vicinity of Bohio and between Gamboa bridge and Caimito Junction.

NUMBER 4. THE CULEBRA FORMATION

The Culebra formation is the oldest series that has, so far, yielded many determinable fossils. Doctors W. H. Dall and T. W. Vaughan regard its fauna as possibly marine Eocene, but very likely Lower Oligocene. When they have carefully studied the collections, the question of age will be cleared up. The formation consists of an upper and a lower member. The lower member (*a*) consists of dark, well laminated beds of soft shales, marls, and carbonaceous clays, with some pebbly, sandy, and tufaceous layers, and a few thin beds of lignitic shale. It outcrops in Culebra Cut, near Culebra, and near Pedro Miguel. The upper member (*b*) consists of beds and lenses of sandy limestone to calcareous sandstone, 3 to 10 feet thick, separated by partings of carbonaceous clays and fine-bedded tuffs. This formation seems to be at least 500 feet thick.

NUMBER 5. CUCURACHA FORMATION

The Cucuracha formation consists of greenish, fine-grained clay, with some local Red Beds. It is fairly massive, but contains a few beds of lignitic shale, some lenses of gravel, sandy beds, and one extensive flow of gray andesitic lava about 20 feet thick. It outcrops along the canal near Rio Grande and on both sides of Gold and Contractors hills. Its chemical composition is andesitic, it is cut by some basalt dikes, and is about 400 feet thick.

NUMBER 6. EMPERADOR LIMESTONE

The Emperador limestone lies unconformably on several of the older beds. It is a light-colored, fairly pure limestone, which contains many corals, some pelecypods, and other marine fossils. Its outcrops are somewhat flaggy and occupy comparatively small areas. Near Las Cascades a section cut by the canal shows five distinct beds, some of which are marly sandstone. The lower beds are 4 to 6 feet and the upper one about 25 feet thick. The formation outcrops northwest of Empire, south of Las Cascades, on the relocated line of the Panama Railroad near San Pablo, near Frijoles, in the swamp southeast of Diablo Ridge, and extensively near Alhajuela. This limestone is referred by Doctors Dall and Vaughan to the Lower Oligocene.

NUMBER 7. CAIMITO FORMATION

The Caimito formation consists of four parts, any one of which may be absent. These are (*a*) a light gray marly argillite, which overlies the Emperador limestone; (*b*) a yellowish and somewhat spherical weathering argillitic sandstone, which is bluish gray on fresh fracture; (*c*) a peculiar calcareous conglomerate with some fragments of much decayed basic rock, which locally gives a bright green stain to small patches of the formation; (*d*) more yellowish spherical weathering argillitic sandstone. "*A*" is found mostly overlying the limestone and in immediate contact with it; "*b*" and "*d*" may be seen in the section at Bald Hill, north of Miraflores, and "*b*" is thought to be the rock which outcrops in the Chagres River at Barbacoas, near San Pablo. "*C*" outcrops at Bald Hill, extensively at San Pablo, and at the site of the proposed wireless telegraph station opposite San Pablo. This whole formation has at least 400 feet of thickness.

NUMBER 8. PANAMA FORMATION

The Panama formation, first named by Hill in his bulletin on the geology of Panama, is a light-colored, well-bedded tuff somewhat acid in composition and locally containing beds of argillite and sandy marl. It has a few fossils and outcrops extensively from Miraflores to Panama and locally in some other places. The formation is at least 400 feet thick and overlies the Caimito beds.

NUMBER 9. GATUN FORMATION

This formation consists of three members: (*a*) About 500 feet of marls and argillites containing many marine fossils and some beds of soft sandstone and conglomerate. It is dark gray in color, except locally, where many brown specks indicating fragments of organic material are shown. (*b*) Mostly fine, soft sandstone for about 100 feet thick, containing a few fossile. (*c*) Light-colored, indurated clay beds. The formation is very extensive and constitutes the foundation on which the Gatun locks are built. The upper part of the formation weathers into red clay: and, except where this is cut through by streams, it covers the solid rock to a depth of 20 to 25 feet. Large collections of fossils have been made from these beds, and from a study of them it is known that the formation was deposited in Oligocene time. The light-colored, indurated clay beds forming the upper part of the Gatun series seem to correspond to the Panama formation, while the Caimito formation is probably the equivalent of the middle and the lower Gatun beds.

NUMBER 10. CARIBBEAN LIMESTONE

The Caribbean limestone (Gabb's antillite) is a sandy fragmental limestone, locally a coquina or shell marl. It fringes the Caribbean coast, forming low bluffs on many of the headlands. Near the river mouths and the lower ends of valleys it is generally absent. It outcrops at Toro Point, west of Gatun Dam, at the mouth of the Chagres River, and is the rock from which Fort San Lorenzo was built. From its fossils it is provisionally referred to the Pliocene. In Costa Rica this limestone fringes the Caribbean shore in many places, and inland from it are argillite beds of the same age.

NUMBER 11. PLEISTOCENE FORMATIONS

These consists of (*a*) bench gravels up to 100 feet above present river levels; (*b*) Swamp formations filling old channels to depths of 375 feet below present sealevels; (*c*) river gravels 10 feet above present flood-plain levels; old sea beaches 6 to 10 feet above present beach levels; (*d*) shoals, beaches, and present river alluvium.

The old channels mentioned under (*b*) were cut out by the rivers when the land stood at least 400 feet higher than it now is. It then slowly sank to about 8 feet below its present level. Its last motion was upward 8 feet, as shown by the geologically very recently raised beaches west of Limon Bay, and at many other points westward into Costa Rica.

IGNEOUS ROCKS

The groups of igneous rocks are: (1) Quartz diorites and granitic rocks, such as that of Cocovi Island and the granitic float locally found in the Chagres River wash, indicating granite outcrops somewhere within the river valley; (2) andesitic rocks, as at Point Farfan, opposite Balboa, locally in Culebra Cut, and at other places within the Chagres River basin, as evidenced by the andesite pebbles in the wash of that river; (3) rhyolitic rocks, as at Ancon Hill, the rock used in the concrete of the Pacific locks; (4) basalts, as at Paraiso, the top part of Gold Hill, near Rio Grande, and locally as dikes in Culebra Cut, as well as at many other places within the Canal Zone; (5) mud lava flows and breccias, as shown locally between Empire and Las Cascades; (6) meta-sediments and breccias, some of which may have been pushed up cold, as crown masses on top of basalt intrusions. Genetically these latter rocks are a peculiar and distinct type, which, so far as known, have not previously been described in geology. Gold Hill, Contractors Hill, and Empire bridge breccia and some of the Paraiso breccias are of this type.

GEOLOGICAL LIGHT FROM THE CATSKILL AQUEDUCT

BY CHARLES P. BERKEY

DISCUSSION

Dr. J. W. SPENCER: The topographic features of the Hudson Valley suggests that the Highlands, near West Point, formed a dividing ridge, from which the drainage passed both southward to New York Harbor and northward to Champlain and the Saint Lawrence, although it is now trenched by the river channel. The country has risen in post-Glacial times to the north, as shown by Woodworth, but so far this deformation and the filling of the buried channels is not sufficient to account for the depth of the pre-Glacial valley at Storm King, but deeper channels may be found. In the meanwhile there is a disposition to conclude that it was due to glacial erosion; but, if so, how did it occur in the very hard rocks when the lake basins in soft rocks were not due to glacial erosion? This question needs to be answered. Recent gravity measurements suggest a faulting in this region, and much must be learned before the origin of the deep channel at Storm King can be explained.

A CLASSIFICATION OF MARINE DEPOSITS

BY AMADEUS W. GRABAU

(*Abstract*)

Of the published classifications of marine deposits that of Murray and Renard (*Challenger* report) is perhaps the best known, being generally found in text-books. Its three main divisions into deep sea, shallow water, and littoral, or shore, are based on the locality of deposition, the source and character of the material receiving only minor consideration. While convenient, such a classification can not be considered strictly scientific. Otto Krümmel (Handbuch der Ozeanographie, Band I, p. 152) gives a more satisfactory subdivision, though his divisions are not always of the same type.[1] He uses the term littoral in the wide sense, including the region from high water to the edge of the continental shelf, a use of the term which to me seems the most logical and satisfactory, as elsewhere advocated.

In any logical classification of marine deposits the distinction between areas of deposition and types of deposits must be clearly kept in mind. The areas of deposition comprise (1) the *littoral district*, with its two zones, (*a*) the *shore* and (*b*) the *neritic;* (2) the *bathyl district*, and (3) the *abyssal district*. Oceanic deposits must be classified first as to their origin and next as to their mode of occurrence. This is aimed at in the following table of oceanic deposits:[2]

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[1] For a statement of Murray's and Krümmel's classification, with criticism, see A. W. Grabau: "Principles of Stratigraphy," pp. 643-645.

[2] For details see A. W. Grabau: "Principles of Stratigraphy," chapters ix (chemical), x and xi (organic), and xv (clastic) deposits.

A NEW CLASSIFICATION OF MARINE DEPOSITS

I. MARINE HYDROGENICS (HALMYROGENIC) deposits, or chemical precipitates from the sea-water.

II. MARINE BIOGENICS, or organic deposits of marine origin.

- A. BENTHONIC, or living on the sea-bottom.
  - 1. *Littoral*—originating in littoral district.
    - *a. Shore zone:*
      - (1) autochthonous, or growing *in situ.*
      - (2) allochthonous, or cast up from deeper water.
    - *b. Neritic or shallow-water zone:*
      - (1) autochthonous—growing *in situ.*
      - (2) allochthonous—transported usually from shore zone.
  - 2. *Bathyal* (between 200 and 900 meters; the bathyal zone):
      - (1) autochthonous.
      - (2) allochthonous—transported usually from littoral zone.
  - 3. *Abyssal* (below 900 meters in depth):
      - (1) autochthonous.
      - (2) allochthonous—transported from the littoral or bathyal regions.
- B. PELAGIC, or living in the open ocean and its extension into the shore indentations, either as plankton or nekton.[3]

These may settle in the Littoral, Bathyal, or Abyssal districts, remaining either in place or more or less rearranged or worked over, especially in shallow water, whence they may be cast on shore and even blown inland. In the Bathyal and Abyssal districts they form pure organic oozes.

III. MARINE CLASTICS. Fragmental material worn off by or in the sea.

- A. HYDROCLASTICS—worn off or rearranged by the sea-waves or currents.
  - 1. *Terrigenous*, or land derived:
    - *a.* from continents, including continental islands.
    - *b.* from oceanic islands, exclusive of coral reefs and other organic deposits.
  - 2. *Thalassigenous*, or sea-derived:
    - *a.* organic lime-sand and mud, derived from coral reefs, from nullipore reefs, shell deposits, etcetera.
    - *b.* derived from halmyrogenic or chemical deposits. Clastic material derived by destruction by waves of chemical deposits formed by the sea (not positively known). Chemically formed marine oolites when worn by waves may come under this head.
- B. BIOCLASTICS—rock material broken up by marine organisms.

Marine bioclastics. These may be classed according to the source from which the material was originally derived, as:

1. *Terrigenous*, from continents and islands.
2. *Thalassigenous*, from coral reefs, etcetera.

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[3] Ibid., p. 991.

IV. MARINE DERELICTS, or stragglers from other realms. These may be deposited in the Littoral, Bathyal, or Abyssal districts.

- A. LAND-DERIVED, either from continents or islands.
  - 1. *Terrestrial*, derived from the land:
    - *a*. *Organic*—land plants or animals floating out to sea or rafted seaward (as under *b*) and deposited in the Littoral, Bathyal, or Abyssal districts. (Microorganisms blown out to sea with the dust would also be classed here.)
    - *b*. *Inorganic*—rocks, sand, gravel, etcetera, rafted from land and deposited in the Littoral, Bathyal, or Abyssal districts. According to the method of transport, we have:
      - (1) *plant rafted*—rocks, etcetera, held by roots of floating trees, etcetera.
      - (2) *animal rafted*—stones in stomach of modern sharks and seals, and of Jurassic Mystriosaurus and Plesiosaurus, as well as in the stomachs of many land animals which may float out to sea.
      - (3) *ice rafted*—by icebergs and floating ice-cakes.
      - (4) *wind rafted*—wind-blown dust or sand, and volcanic material brought from the land.
      - (5) *ship rafted*—substances carried out by ships or man-made rafts and cast overboard or deposited on the foundering of the ship.
      - (6) carried into the sea by slipping or gliding.
  - 2. *Aquatic*—derived from the rivers and estuaries. This would comprise chiefly river animals and plants which have been carried out to sea.
  - 3. *Derived from adjacent higher zone* by gliding or thrusting.

B. ATMOSPHERICALLY DERIVED.

Since the chief atmogenic solids, *snow* and *hail*, have only a temporary existence, deposits from this source may be neglected. Rare cases of *organisms*, such as sea-birds, which spend most of their lives in the air, might perhaps be included here, but they may as well be classed with terrestrial derelicts.

C. METEORIC, OF EXTRATELLURIC ORIGIN.

Here belong the cosmic dust and the meteorites.

D. OF SUBCRUSTAL ORIGIN.

This includes volcanic eruptions beneath the sea and on the coast, so that both pyrogenics and pyroclastics flow or are projected into the sea. The direct pyroclastics merge, of course, into the wind-transported pyroclastics.

DISCUSSION

Prof. J. BARRELL: A classification makes for sharpness of thought and must precede analysis, so that I am in general sympathy with Professor Grabau on the purpose and propositions of his paper "A classification of marine deposits," but I wish to make a few comments on details.

There is objection to the use of the word "littoral" in the vague sense here employed. The dictionaries define "littoral" as the zone of shore between high and low tide. Such a zone has definite geologic and biologic characteristics. It seems unfortunate, then, that a loose and vague use of this word should be given scientific sanction merely because certain zoologists have so employed it.

There is also a question if for present purposes so much use need be made of the Greek language for terms but seldom used. For example, "shallow sea deposits" is a term perfectly clear and quite as sharp as the Greek form used in this classification. A system of classification should require as little memorizing of unfamiliar terms as possible in order to command its acceptance.

On one division of Professor Grabau's classification I wish to place emphasis. It may have seemed that his divisions of "rafted material" illustrated pushing a classification to a futile extreme. On the contrary, I have been impressed with Darwin's statement that at a distance of several hundred miles from the shores of the Sahara the water was perceptibly colored by dust blown from the desert. Off the leeward shores of Australia the same phenomenon has been noted; there the air and water are at times laden with dust. The abundance of finer clastic material which is carried in this way suggests that a considerable source of the clay of certain ancient argillaceous limestones may be from wind-borne dust—eolian deposits of the sea.

Material rafted by trees and ice must also contribute perceptibly to certain deposits, when we consider the slowness of accumulation on the bottom of the deep open seas of water-borne material settling from suspension. The *Challenger* expedition in one dredge-load from the central Pacific recovered 1,500 sharks' teeth and 50 ear bones of whales, which means that if all the life were put back into the sea which had existed during this accumulation many sharks and whales would have to occupy at the same time the narrow vertical prism of water above this piece of bottom. In view of this slowness of natural deposition, man has become, as in many other regions of the earth, an important geological agent. The oxidized and inorganic debris which he throws overboard from ships must already mark out the steamer lanes across, especially the abyssal ocean bottoms. The unalterable materials which he contributes most abundantly to the deposits of the sea are coal ashes, broken dishes, and bottles. These are being permanently incorporated in the crust. They will endure long after the monuments which he erects above baselevel shall have crumbled and been removed by erosion. These geologic records will be uplifted and exposed in places by future crustal movements and shall link the distant future to that past which is the present. It is seen in the light of these facts that the name being recorded most widely and indelibly on the earth at the present time is the name of him who made Milwaukee famous.

POSTGLACIAL EARTH MOVEMENTS ABOUT LAKE ONTARIO AND THE SAINT LAWRENCE RIVER[1]

BY J. W. SPENCER

Published as pages 217-228 of this volume.

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[1] Presented at the meeting under the title "Extended determination of postglacial earth movements from the Lake region to the Saint Lawrence Valley."

DISCUSSION

Prof. D. W. **JOHNSON** wished to know how far errors in determining the ancient water plane at different places along the abandoned shorelines would introduce errors into the determinations of presence or absence of present tilting.

Referring to a question raised by Professor Davis, Professor Johnson pointed out that Goldthwait's work on the abandoned shorelines along Lake Michigan seemed to show that ancient tilting did not affect the southern part of that region, but increased toward the north.

Dr. **SPENCER** replied: In determining the deformation by triangulation of the heights of the tilted beaches at various points, the measurements are very close and the figures large, so that for all points west of Watertown the results practically eliminate the personal equations. East of Watertown fuller measurements may slightly modify the results, but these may be taken as approximately correct.

While the location of the maximum deformation is near latitude 49° north, longitude 76° west. the axis appears to follow that of the Laurentian Highlands, as suggested by Dana and Goldthwait. Accordingly, the deformation in the Michigan and Superior district trends to the mountain zone west of the region of maximum deformation, which is the most southern lobe of the Laurentian Highlands. The same should be true for the country to the east.

While the rate of movement increases to the northeast or north, it decreases to almost zero about the head of Lake Erie and Lake Michigan, so that the deformation disappears in the interior of the continent. All of these features are found in the tilted beaches of the Lake region, beyond which other data must be sought to elucidate the recent earth-movements; but some of these are at hand.

NATURE OF THE SUBSTANCE KNOWN AS MOTHER OF COAL AND ITS RELATION TO THE PROCESS OF COAL FORMATION

BY EDWARD C. JEFFREY[1]

(Abstract)

In the greater number of coals there is present a substance variously known as "Mother of Coal," "Fusain," "Faserkohle," etcetera. This has generally been interpreted as the charred remains of wood or as the remains of woody structures which have escaped the process of carbonification, to which the woody tissues in general are subjected in coal. As the result of the investigation of coal by improved methods, which permit of the preparation of successful sections, even of the most resistent coals, such as anthracites, etcetera, the author has satisfied himself, by the examinations of coals of wide geological and geographical range, that the so-called mother of coal is in reality the charred, or partially charred, vestige of woody structures. Its presence in the coal is accordingly an interesting problem. It has been made out in all the cases yet examined that mother of coal is invariably accompanied by large quantities of flattened spores, and the general structure of the coals in which it has been studied is such as to warrant the conclusion that they have been laid down under open water. It follows that coals containing mother of coal are not derived from the transformation of peat bogs into coal, as is almost universally assumed, but owe their origin to sedimentary deposits of vegetable matter in open ponds or lakes. Since the presence of mother of coal in coals other than cannels and boghead or oil shales is almost universal, it follows that our ideas of the conditions under which coal has been formed must be very radically modified. It follows also that the question of the conservation of coal deposits has an added importance from the realization of the extreme slowness with which they have been formed. The paper is illustrated by a number of colored photomicrograms of coals of the United States, Europe, and Australasia.

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[1] Introduced by David White.

POTTSVILLE-ALLEGHENY BOUNDARY IN THE INTERIOR PROVINCE

BY DAVID WHITE

(*Abstract*)

The Coal Measures of these States do not so frequently contain well preserved plant remains as do those of the Appalachian trough, on account of the nearness of the coal-forming swamps and marshes to sealevel and the frequent submergence beneath salt or brackish water when the rate of subsidence was too great or protective barriers were breached, thus sometimes permitting the invasion of shoal-water marine molluscan faunas over the areas of underlying peat. The paleobotanic material in hand indicates early Allegheny age for coal "No. 2" (Murphysboro, Colchester, Mazon Creek coals) of Illinois, and the reference of coal "No. 1" to the Pottsville, the associated stoneware clays of the State being distinctly Upper Pottsville (probably Connoquenessing) in age. On both paleobotanic and stratigraphic grounds the Bevier coal of the Missouri fields is regarded as probably equivalent to coal "No. 2" of Illinois, the Tebo coal, next lower in Missouri, being apparently of Upper Pottsville age. In both basins the Pennsylvanian sea entered from the south, permitting the deposition of earlier beds to the southward, and, toward the close of Pottsville time, encroached on the old land to the north throughout a region including the greater part of the present coal-field area. In Missouri the overlap was strongly northeastward.

ORIGIN OF THE HARD ROCK PHOSPHATE DEPOSITS OF FLORIDA

BY E. H. SELLARDS

(*Abstract*)

Some of the problems to be accounted for in the origin of the hard rock phosphate deposits of Florida are: (1) The source of the phosphate and of the other materials of which the deposits are made up, including sands, clays, flint pebbles, phosphate and flint boulders, and limestone inclusions; (2) the intimate admixture in the deposits of these diverse materials; (3) the processes by which the phosphate and flint boulders have formed; (4) the localization of the workable deposits of phosphate; (5) the limitation of the hard rock phosphate area to a particular and well marked physiographic type of

country. The explanation offered is as follows: The Upper Oligocene formations and some later deposits, now found on the uplands bordering the hard rock phosphate fields, formerly extended directly across the country that is now the hard rock phosphate area. The disintegration of these formations supplied the miscellaneous material of which the deposits are composed; the solution of the underlying Vicksburg limestone permitted irregular and interrupted subsidence through the formation of sinks, accounting for the mixing of these materials; the phosphoric acid was supplied from these overlying deposits, particularly from the Upper Oligocene formations, which are known to be very generally phosphatic throughout their entire extent over western, northern, and central Florida; the phosphate and flint boulders were formed chemically through the agency of percolating water; the hard rock deposits are localized because the material in which they accumulated is lacking in uniformity; local variations, particularly the presence of clay lenses, and other conditions which interfere with the free circulation of water favored the formation of phosphate boulders; the plate rock represents fragments of disintegrated boulders; the hard rock phosphate deposits are limited by reason of their mode of origin to a particular stage of physiographic development, in which phosphate-bearing formations have disintegrated overlying a limestone substratum, thus forming conditions favorable for the downward movement of rain water carrying the phosphoric acid which reaccumulated at a lower level.

ALTERATION PROCESSES AND PRODUCTS WITHIN THE GRENVILLE LIMESTONE

BY ALEXIS A. JULIEN

(*Abstract*)

The following views have been derived chiefly from study of the Grenville formation during several visits to Hull, Argenteuil, Ripon, Grenville, North Burgess, etcetera, Canada, and to the Adirondack regions. The phenomena to which the Grenville limestones owe their special interest are found to be simply explained, partly by the reactions involved during alteration of the dolomite (for example, "eozoon" structure) and partly (graphite and apatite) by probable derivation from alteration of early organic forms—vegetable and animal.

In the Grenville limestone proper the evidences of derivation from detrital sediments (rather than chemical precipitation) consist of the observed repetitions of detrital and calcareous deposits, the peculiar lamination, and the abundant distribution of graphite and apatite. The chief agencies of alteration have been first magnesian and then siliceous solutions, resulting in two great processes. First, dolomitization; after consideration of hypotheses, it is concluded that this has been due to saturation by magnesian solutions descending from a laterite cover. The subsequent process, silicification, was twofold. Its earlier action was effected by thermal waters, also derived from the laterite. The chief product was pyroxene rock after dolomite, with release of calcium carbonate in alternation (first variety (*a*) of "eozoon" structure). Equal objections are advanced against the hypotheses of Dawson and of King and Romney. Other forms produced by different conditions comprised phlogo-

pite and biotite after dolomite ("eozoon" *b*); antigorite after pyroxene ("eozoon *c*); loganite after pyroxene, phlogopite, etcetera ("eozoon" *d*); alternation of pyroxene and apatite ("eozoon" *c*). The later form of silification was effected by meteoric waters, resulting in antigorite after dolomite ("eozoon" *f*) and antigorite after nemalite, chrysotite ("eozoon" *g*).

A secondary result of the same processes appear in the calcite-pegmatite veins, peculiar to the Grenville formation. These may be coarse granitic or banded, and their constitution is shown by a large number of cross-sections, and the source of the calcite deduced from reactions in the processes of silification. On the derivation of the apatite in these veins and in the limestone beds various hypotheses are considered, but it is attributed to a process of concentration during the silification of the dolomite.

NEW LIGHT ON THE KEWEENAWAN FAULT

BY A. C. LANE

(Abstract)

Recent exploration and drilling have shown that the strata on the east side of the Copper Range were uplifted and the Eastern or Jacobsville sandstone deposited on them, and that since then, by a great fault, the Trap Range has overridden these sandstones in certain places several hundred feet. There was a peneplanation (Cretaceous ?) subsequently, but the Keweenawan rocks were not so peneplaned when the Eastern-Jacobsville sandstone was laid down but that pebbles of the Keweenawan traps occur in it.

GLACIAL EROSION IN THE GENESEE VALLEY SYSTEM AND ITS BEARING ON THE TERTIARY DRAINAGE PROBLEM OF EASTERN NORTH AMERICA

BY AMADEUS W. GRABAU

(Abstract)

The evidence for glacial overdeepening of the Warsaw, Genesee, and Dansville valleys will be given, and from the pre-Glacial arrangement of the stream valleys the question of northward or southward drainage in New York during Tertiary time will be considered.

DISCUSSION

Dr. J. W. **SPENCER**: The drainage of the Canadian Highlands at an early date was doubtless to the south, but the encroachment of the Saint Lawrence River and tributaries lowered the northern country and robbed the heads of the southbound streams. The apparent post-Glacial rise is everywhere northward, so that the region of Ontario was relatively lower than now. When the continent stood high, before the Glacial or during the Glacial period, the greater northern elevation, as shown in the submerged channel of the Gulf of Saint Lawrence and of the Hudson River, also obtained all the way to the Gulf of Mexico, as found by the buried valleys. Accordingly, when the floor of Lake Ontario is found to be 1,400 feet lower than the rock floor which crosses the head of the Dundas Valley, there is no evidence whatever that the tilting was in the direction or of necessary amount to turn the drainage from the depths of Lake Ontario to the southwest. The buried Erigan and other tributary valleys to that of Ontario are all against former drainage up the Dundas Valley converging toward the west.

ROOTS IN THE UNDERCLAYS OF COAL

BY DAVID WHITE

(*Abstract*)

On a close inspection the floor, usually an "underclay," beneath the coal beds in the American coal fields is, in the great majority of cases, found to contain roots of vascular plants in their place of growth. The prevalent occurrence of such roots of various kinds, which are to be seen under the commercially workable coals in all fields examined, whether of Tertiary, Mesozoic, or Carboniferous age, clearly indicates that in most areas at least the coal swamps were not too deeply submerged or inundated to permit vascular plants to root and grow in place at the commencement of the formation of the mother peat. In some cases evidence points also to the growth of arborescent vegetation on the surface of the growing peat. Such growth unquestionably occurred on the partings of certain coals and was not infrequent in the roofs of the submerged peats.

OBJECTS AND METHODS OF PETROGRAPHIC DESCRIPTION

BY CHARLES P. BERKEY

(*Abstract*)

The object in most descriptions seems to be to lay a foundation for the conclusion, which is usually the name of the rock, yet there is almost always much more detail than is used for such purpose. This is so prominent occasionally that the most apparent object seems to be to record as much detail as the investigator can determine. It is quite certain, however, that the real object of many such studies is a quite different and much more complicated matter—no less, indeed, than determining as fully as possible the life history of the rock. The object, in other words, is rock interpretation instead of classification in its simplest form.

Forms for recording data for use in the simpler cases were presented.

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